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HANDBOOK FOR SEWER SYSTEM EVALUATION AND REHABILITATION

DECEMBER 1975
TECHNICAL REPORT

U.S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF WATER PROGRAM OPERATIONS
WASHINGTON, D.C. 20460

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HANDBOOK
FOR
SEWER SYSTEM EVALUATION
AND REHABILITATION

Municipal Construction Division
Office of Water Program Operations
Environmental Protection Agency
Washington, D. C. 20460

December 1975

MCD-19

Foreword

The extraneous flow associated with infiltration-inflow (I/I) has long been recognized as a major factor in treatment facility performance. The impact on stream pollution has been so great that the subject of I/I must be fully addressed in any realistic water pollution control program. For this reason, the Federal Water Pollution Control Act Amendments of 1972 requires that after July 1, 1973 all grant applicants must identify and correct excessive I/I for each sewer collection system discharging into treatment works proposed for grant assistance. The requirement was implemented in the Construction Grant Regulations, Section 40 CFR 35.927, and in the Guidance for Sewer System Evaluation published in March 1974.

This handbook is not a design manual. It is primarily a supplement to the Guidance for Sewer System Evaluation and accordingly, it contains technical information and describes the methodology necessary for an effective investigation and correction of I/I conditions in a sewer system. Also included is a set of cost curves showing the correlation between the cost for each phase of sewer system evaluation work and variables such as sewer length, population, and magnitude of I/I. Additionally, the handbook contains a special chapter entitled "User's Guide". It is emphasized that this chapter should be carefully read before using the manual.

The handbook does not contain any regulatory materials or mandatory requirements. To the contrary, it is designed to provide a wide range of information on conditions found in all the various types of sewer systems. For this reason, it is essential that the user of the handbook select only those techniques applicable to a particular system in order to generate the necessary information. Brevity and simplicity are encouraged.

It is the intention of the Environmental Protection Agency to revise and update this handbook as new and improved techniques are developed through experience. All users are encouraged to submit any pertinent information to the Director, Municipal Construction Division (WH 547), Office of Water Program Operations, U.S. Environmental Protection Agency, Washington, DC 20460.

Andrew W. Breidenbach
Assistant Administrator
Water and Hazardous Materials

NOTICE

THIS REPORT HAS BEEN REVIEWED BY EPA, AND APPROVED FOR PUBLICATION. APPROVAL DOES NOT SIGNIFY THAT THE CONTENTS NECESSARILY REFLECT THE VIEWS AND POLICIES OF THE ENVIRONMENTAL PROTECTION AGENCY, NOR DOES MENTION OF TRADE NAMES OR COMMERCIAL PRODUCTS CONSTITUTE ENDORSEMENT OR RECOMMENDATION FOR USE.

ABSTRACT

Guidance has been provided to assist in the preparation and review of Infiltration/Inflow Analyses and Sewer System Evaluation Surveys. In addition, information is given on the techniques of sewer rehabilitation and the costs related to Evaluation Survey and Rehabilitation.

The handbook contains chapters on: (1) methodology for conducting I/I Analysis, (2) methodology for conducting Sewer System Evaluation Survey, (3) information on current state-of-the-art techniques for sewer rehabilitation and (4) costs associated with conducting Sewer System Evaluation Survey and rehabilitation.

The chapters on methodology explain in detail each of the specific tasks that may be required in conducting I/I Analysis and Sewer System Evaluation Survey. The methodology presented is proven current state-of-the-art techniques. Other techniques not presented may be applicable and their use is encouraged. The sewer rehabilitation techniques presented have been obtained from specialists in the particular field and are provided for information purposes only.

To assist in proper use of this handbook, a chapter on User Guide is prepared (Chapter 2). THE READER SHOULD READ THAT CHAPTER BEFORE GOING THROUGH OTHER CHAPTERS.

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CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

The Water Pollution Control Act Amendments, Public Law 92-500, dated October 18, 1972 requires construction grant applicants to investigate the condition of their sewer systems. Title II, Section 201 (g) (3) of the Law states, "The Administrator shall not approve any grant after July 1, 1973, for treatment works under this section unless the applicant shows to the satisfaction of the Administrator that each sewer collection system discharging into such treatment works is not subject to excessive infiltration".

Title II, Section 201 (g) (4) of the Law states, "The Administrator is authorized to make grants to applicants for treatment works grants under this section for such sewer system evaluation studies as may be necessary to carry out the requirements of paragraph (3) of this subsection. Such grants shall be made in accordance with rules and regulations promulgated by the Administrator. Initial rules and regulations shall be promulgated under this paragraph not later than 120 days after the date of enactment of the Federal Water Pollution Control Act Amendments of 1972".

The final Construction Grant Regulations pertaining to the aforementioned were published in the Federal Register dated February 11, 1974. The following sections in the Construction Grant Regulations pertain to Sewer System Evaluation and Rehabilitation.

§ 35.927 Sewer System Evaluation and Rehabilitation.

(a) All applicants for grant assistance awarded after July 1, 1973, must demonstrate to the satisfaction of the Regional Administrator that each sewer system discharging into the treatment works project for which grant application is made is not or will not be subject to excessive infiltration/inflow. The determination whether excessive infiltration/inflow exists, may take into account, in addition to flow and related data, other significant factors such as cost-effectiveness (including the cost of substantial treatment works construction delay, ...), public health emergencies, the effects of plant bypassing or overloading, or relevant economic or environmental factors.

...

(b) The determination whether or not excessive infiltration/inflow exists will generally be accomplished through a sewer system evaluation consisting of (1) certification by the State agency, as appropriate; and, when necessary (2) an infiltration/inflow analysis; and, if appropriate, (3) a sewer system evaluation survey followed by rehabilitation of the sewer system to eliminate an excessive infiltration/inflow defined in the sewer system evaluation. Information submitted to the Regional Administrator for such determination should be the minimum necessary to enable a judgment to be made.

(c) Guidelines on sewer system evaluation published by the Administrator provide further advisory information.

§ 35.927-1 Infiltration/Inflow Analysis.

(a) The infiltration/inflow analysis shall demonstrate the nonexistence or possible existence of excessive infiltration/inflow in each sewer system tributary to the treatment works. The analysis should identify the presence, flow rate, and type of infiltration/inflow conditions, which exist in the sewer systems. Information to be obtained and evaluated in the analysis should include, to the extent appropriate, the following:

(1) Estimated flow data at the treatment facility, all significant overflows and bypasses, and, if necessary, flows at key points within the sewer system.

(2) Relationship of existing population and industrial contribution to flows in the sewer system.

(3) Geographical and geological conditions which may affect the present and future flow rates or correction costs for the infiltration/inflow.

(4) A discussion of age, length, type, materials of construction and known physical condition of the sewer system.

(b) For determination of the possible existence of excessive infiltration/inflow, the analysis shall include an estimate of the cost of eliminating the infiltration/inflow conditions. These costs shall be compared with estimated total costs for transportation and treatment of the infiltration/inflow. Cost-effectiveness Analysis Guidelines (...), which contain advisory information, should be consulted with respect to this determination.

(c) If the infiltration/inflow analysis demonstrates the existence or possible existence of excessive infiltration/inflow, a detailed plan for a sewer system evaluation survey shall be included in the analysis. The plan shall outline the tasks to be performed in the survey and their estimated costs.

§ 35.927-2 Sewer System Evaluation Survey.

(a) The sewer system evaluation survey shall consist of a systematic examination of the sewer systems to determine the specific location, estimated flow rate, method of rehabilitation and cost of rehabilitation versus cost of transportation and treatment for each defined source of infiltration/inflow.

(b) The results of the sewer system evaluation survey shall be summarized in a report. In addition, the report shall include:

(1) A justification for each sewer section cleaned and internally inspected.

(2) A proposed rehabilitation program for the sewer systems to eliminate all defined excessive infiltration/inflow.

§ 35.927-3 Rehabilitation.

(a) The scope of each treatment works project defined within the Facilities Plan as being required for implementation of the Plan, and for which Federal assistance will be requested, shall define (1) any necessary new treatment works construction, and (2) any rehabilitation work determined by the sewer system evaluation to be necessary for the elimination of excessive infiltration/inflow. However, rehabilitation which should be a part of the applicant's normal operation and maintenance responsibilities shall not be included within the scope of a Step 3 treatment works project.

(b) Grant assistance for a Step 3 project segment consisting of rehabilitation work may be awarded concurrently with Step 2 work for the design of the new treatment works construction.

§ 35.927-4 Sewer Use Ordinance.

Each applicant for grant assistance for a Step 2, Step 3, or combination Steps 2 and 3 project shall demonstrate to the satisfaction of the Regional Administrator that a sewer use ordinance or other legally binding requirement will be enacted and enforced in each jurisdiction served by the treatment works project before the completion of construction. The ordinance shall prohibit any new connections from inflow sources into the sanitary sewer portions of the sewer system and shall ensure that new sewers and connections to the sewer system are properly designed and constructed.

§ 35.927-5 Project Procedures.

(a) State certification. The State agency may (but need not) certify that excessive infiltration/inflow does or does not exist. The Regional Administrator will determine that excessive infiltration/inflow does not exist on the basis of State certification, if he finds that the State had adequately established the basis for its certification through submission of only the minimum information necessary to enable a judgment to be made. Such information could include a preliminary review by the applicant or State, for example, of such parameters as per capita design flow, ratio of flow to design flow, flow records or flow estimates, bypasses or overflows, or summary analysis of hydrological, geographical, and geological conditions, but this review would not usually be equivalent to a complete infiltration/inflow analysis. State certification must be on a project-by-project basis. If the Regional Administrator determines on the basis of State certification that the treatment works is or may be subject to excessive infiltration/inflow, no Step 2 or Step 3 grant assistance may be awarded except as provided in paragraph (c) of this section.

(b) Pre-award sewer system evaluation. Generally, except as otherwise provided in paragraph (c) of this section, an adequate sewer system evaluation, consisting of a sewer system analysis, and, if required, an evaluation survey, is an essential element of Step 1 facilities planning and is a prerequisite to the award of Step 2 or 3 grant assistance. If the Regional Administrator determines through State Certification or an infiltration/inflow analysis that excessive infiltration/inflow does not exist, Step 2 or 3 grant assistance may be awarded. If on the basis of State certification or the infiltration/inflow analysis, the Regional Administrator determines that possible excessive infiltration/inflow exists, an adequate sewer system evaluation survey and, if required, a rehabilitation program must be furnished, except as set forth in paragraph (c) of this section before grant assistance for Step 2 or 3 can be awarded. A Step 1 grant may be awarded for the completion of this segment of Step 1 work, and, upon completion of Step 1, grant assistance for a Step 2 or 3 project (for which priority has been determined pursuant to § 35.915) may be awarded.

(c) Exception. In the event it is determined by the Regional Administrator that the treatment works would be regarded (in the absence of an acceptable program of correction) as being subject to excessive or possible excessive infiltration/inflow, grant assistance may be awarded provided that the applicant establishes to the satisfaction of the Regional Administrator that the treatment works project for which grant application is made will not be significantly changed by any subsequent rehabilitation program or will be a component part of any rehabilitated system: Provided, That the applicant agrees to complete the sewer system evaluation and any resulting rehabilitation on an implementation schedule the State accepts (subject to approval by the Regional Administrator), which schedule shall be inserted as a special condition in the grant agreement. Compliance with this schedule shall be accomplished pursuant to § 35.935-16 and § 30.304 of this chapter.

(d) Municipalities may submit the infiltration/inflow analysis and when appropriate the sewer system evaluation survey, through the State agency, to the Regional Administrator for his review at any time prior to application for a treatment works grant. Based on such a review, the Regional Administrator shall provide the municipality with a written response indicating either his concurrence or nonconcurrence. The Regional Administrator must concur with the sewer system evaluation survey plan before the work is performed for the survey to be an allowable cost.

Draft Guidance for Sewer System Evaluation was circulated on April 27, 1973 and the final Guidance was published in March 1974 by the Environmental Protection Agency.

1.2 PURPOSE

The intent of this Handbook is to present a systematic approach for conducting the evaluations and provide a source of information to assist the applicants in fulfilling the requirements under the Act. An effort has been made to convey the current state-of-the-art in conducting (1) Infiltration/Inflow Analyses, (2) Sewer System Evaluation Surveys, and (3) Rehabilitation. Methodology.

The contents of this Handbook are not intended to be specific requirements that each grant applicant must adhere to, for site-specific conditions may preclude the utilization of the state-of-the-art presented hereinafter. The fulfillment of the requirements under the Act will be based on sound engineering practices and this handbook may be another tool utilized to achieve the desired intent of the Act. In many instances the methodology and specific examples presented will be suited for a sewer system; and for many others, modifications will be appropriate.

1.3 FORMAT

Chapters 3, 4 and 5 of the handbook addresses the methodology in accomplishing (1) Infiltration/Inflow Analyses, (2) Sewer System Evaluation Surveys, and (3) Rehabilitation. (Each specific task is preceded by an overview explaining the purpose and expected information to be generated and then the current methodology is presented.) The methodology consists of an array of techniques that are currently utilized to accomplish the specific tasks. The specific techniques that pertain to the applicant's project may be utilized or other modes of accomplishing the task may be employed.

Chapter 6 of the handbook addresses the cost information which may be utilized in cost-effective analyses. The cost for conducting the Sewer System Evaluation Survey and the resulting rehabilitation are presented. These costs can be used to develop the specific costs for the applicant's project. Again, other cost criteria may be employed for particular circumstances that are not of a general nature. Cost information must be modified, where necessary, to suit local conditions.

The Appendix of the handbook contains a description of State Certification and a glossary of terms used in this handbook.

1.4 OVERVIEW

"Extraneous water from infiltration/inflow sources reduces the capability of sewer systems and treatment facilities to transport and treat domestic and industrial wastewaters. Infiltration occurs when existing sewer lines undergo material and joint degradation and deterioration as well as when new sewer lines are poorly designed and constructed. Inflow normally occurs when rainfall enters the sewer system through direct connections such as roof leaders and catch basins. The elimination of infiltration/inflow by sewer system rehabilitation can often substantially reduce the cost of wastewater collection and treatment. However, a logical and systematic evaluation of the sewer system is necessary to determine the cost-effectiveness of any sewer system rehabilitation to eliminate infiltration/inflow.

The Federal Water Pollution Control Act Amendments of 1972 require that after July 1, 1973, all applicants for treatment works grants must demonstrate that each sewer system discharging into the treatment works is not subject to excessive infiltration/inflow. The requirement was implemented in the Rules and Regulations for Sewer System Evaluation and Rehabilitation, 40 CFR 35.927.

This document is intended to provide engineers, municipalities, and regulatory agencies with guidance on sewer system evaluation."

The three aforementioned paragraphs constituted the Introduction of the March 1974 Guidance for Sewer System Evaluations and also provide a suitable introduction for the Overview of this Handbook.

The U.S. Congress, U.S. Environmental Protection Agency and those involved in the wastewater field recognize the economic significance of extraneous water in sewer systems. Public Law 92-500, the Rules and Regulations for Sewer System Evaluation and Rehabilitation, the March 1974 Guidance for Sewer System Evaluations and this handbook have all been developed with the expressed intent of optimizing the expenditure of funds allocated by Congress for municipal pollution abatement facilities.

The U.S. Environmental Protection Agency has taken the approach that sewer systems tributary to treatment works for which an EPA construction grant will be used, should be investigated sufficient to determine the infiltration/inflow conditions. Those systems that contain excessive infiltration/inflow will be eligible for construction grant assistance for rehabilitation of the sewer system to eliminate these flows. The Construction Grant Regulations specifically state that, "Rehabilitation which should be a part of the applicant's normal operation and maintenance responsibilities shall not be included within the scope of a Step 3 treatment works project."

Thus it is not the intent of the Sewer System Evaluation Program to rehabilitate all sewer systems nationwide that are or will be involved in the Construction Grants Program but rather to ensure that infiltration/inflow is addressed and reasonableness is utilized when evaluating those sewer lines which will ultimately be rehabilitated.

This program can be successfully implemented by the following:

- Flexible Interpretation of the Rules and Regulations and Guidance - A good communicative relationship between the Regulatory Agencies, the grant applicant and those providing services for the applicant can result in a workable solution for the most complex situation. This handbook should point out some of the solutions but others will have to be devised for specific problems that are encountered.

- Documentation of pertinent data in the Infiltration/Inflow Analysis Reports and Sewer System Evaluation Survey Reports - Sound engineering practice has always dictated that Infiltration/Inflow should be investigated to some degree in sewer systems that are to be expanded or upgraded. The documentation of this type investigative work may have been limited in the past. It is good practice to document this information in the Analysis or Survey Reports. This handbook will demonstrate techniques to accomplish specific tasks which may or may not be a component part of Analysis or Survey Reports. Other techniques specific to an applicant's need may be utilized.

- Development and/or continuation of operation and maintenance programs for the applicant's sewer system - Many municipalities have extensive O & M programs and the continuation of these programs will have a greater beneficial impact on the sewer system and treatment facility than the selective rehabilitation that may be funded under Public Law 92-500 due to excessive extraneous water. Many other Municipalities have limited or no O & M programs and they are advised to take cognizance of the derived benefits of a good program. The resulting selective rehabilitation that is funded under Public Law 92-500 will not solve sewer problems that were marginally nonexcessive or that may deteriorate before the life of the treatment works is attained. This handbook does not present criteria for O & M programs but the data generated from conducting Infiltration/Inflow Analyses and Sewer System Evaluation Surveys form a sound basis for developing such programs.

1.5 IMPLEMENTATION

The implementation of Sewer System Evaluation and Rehabilitation is documented in the February 11, 1974, Construction Grant Regulations, sections 35.927 through 35.927-5. The reader is advised to review these important paragraphs which have been presented in Section 1.1 of this Chapter.

These aforementioned Rules and Regulations have a considerable degree of flexibility which should permit a realistic solution to the more complex situations. It is imperative that U.S. EPA and State Regulatory Agency personnel, grant applicants and those providing services for grant applicants be thoroughly familiar with these Rules and Regulations. The Grant applicant and his consultant should meet with EPA and the respective State regulatory personnel to discuss the specific project and the scope of work.

CHAPTER 2

USER'S GUIDE

2.1 INTRODUCTION

The data contained in this Handbook for conducting Sewer System Evaluations are voluminous and in specific detail. The intent of this Handbook is to present sufficient information which will enable engineers and reviewers to prepare and/or review Sewer System Evaluations on the vast array of circumstances that are encountered in various sewer systems. Because of the varying circumstances that are encountered in sewer systems all of the methodology presented hereinafter will not apply to each project.

This User's Guide is presented to emphasize that only specific portions of the methodology that applies to the project under study should be utilized.

2.2 INFILTRATION/INFLOW ANALYSIS

The intent of the Infiltration/Inflow (I/I) Analysis (see Chapter 3) is to establish possibly excessive or nonexcessive I/I in an expedient and thorough manner. In order to accomplish this, an I/I Analysis should contain:

- Background Information
- Determination of I/I
- Establishment of Possibly Excessive or Nonexcessive I/I

The engineer should always make a first attempt to conduct an I/I Analysis by utilizing all pertinent existing data. If this cannot be accomplished, then minimum data must be generated which will permit the engineer to complete the I/I Analysis.

A check list is presented which may be utilized by the engineer to determine the components of an I/I Analysis which are pertinent to the project under study. It is essential that only the components which will allow successful completion of the I/I Analysis be considered.

The check list contains a listing of functions and corresponding subheading and page numbers. In addition, a rating of importance for each function is listed. The following is a general description of the rating system employed:

- Rating No. 1 - This indicates an essential function which should be considered for every I/I Analysis. An attempt should be made to perform the function by utilizing existing data. The use of minimum data is encouraged.

- Rating No. 2 - This indicates a function which may/or may not be required to complete the I/I Analysis. It is a function which provides supporting data for a No. 1 function. An attempt should be made to perform the I/I Analysis without these functions; but if it is considered necessary, the use of minimum data is encouraged.

2.3 SEWER SYSTEM EVALUATION SURVEY

The Sewer System Evaluation Survey (see Chapter 4) is a systematic examination of the sewer system to locate all infiltration and inflow sources which were previously determined to be possibly excessive, determine the flow rate from each source and estimate the costs required for the rehabilitation of the system. Chapter 4 presents the methodology for conducting Sewer System Evaluation Surveys. A particular project may require any number of the functions presented.

A check list is presented which may be utilized by the engineer to determine the components of a Sewer System Evaluation Survey which are pertinent to the project under study. The check list contains a listing of functions and corresponding subheading and page numbers. In addition, a blank space is provided for a check mark or comment.

2.4 SEWER SYSTEM REHABILITATION

The Sewer System Rehabilitation Chapter (see Chapter 5) of this handbook describes the various rehabilitation techniques that are commonly utilized for sewer systems. The information presented in that Chapter is for information purposes only. The engineer is encouraged to read this Chapter in order to become familiar with specific rehabilitation techniques.

2.5 COSTS

Costs for conducting Sewer System Evaluation Surveys and Rehabilitation are presented in Chapter 6. The cost information presented should be used in the cost-effectiveness analysis of the I/I Analysis. The costs should be refined for a particular study when used in the cost-effectiveness analysis of the Sewer System Evaluation Survey.

The engineers preparing Sewer System Evaluations and the Regulatory personnel reviewing the projects should read and understand the sources and intent of the costs presented in Chapter 6. In order to effectively use the costs, the following items should be understood:

- Tables 6-1 and 6-9 and Figures 6-25 to 6-27 show the costs for conducting Sewer System Evaluation Surveys and Rehabilitation. These costs can be used in the I/I Analysis after they have been adjusted for the particular sewer system under study by analyzing the cost criteria presented in Tables 6-2 to 6-8.

- The aforementioned cost tables and figures can only be utilized in the Sewer System Evaluation Survey Phase after incorporating the cost criteria for the specific rehabilitation required in the system under study.

- Figures 6-1 to 6-24 display the costs for conducting Sewer System Evaluation Surveys and should only be used in a preliminary manner, i.e., by Regulatory personnel when establishing an order of magnitude in determining the reasonableness of costs presented in I/I Analysis report.

TABLE 2-1

CHECK LIST FOR CONDUCTING INFILTRATION/INFLOW ANALYSIS

Function	Subheading No.	Page No.	Rating
BACKGROUND INFORMATION	3.2	3-3	1
Interview	3.2.1	3-3	2
Sewer Map Analysis	3.2.2	3-16	2
Inventory of Existing Sewer System	3.2.3	3-21	2
Geographic and Geological Data	3.2.4	3-25	2
Wastewater Flow Data	3.2.5	3-34	1
Flow Measurement	3.2.6	3-35	2
Physical Condition of Sewer	3.2.7	3-56	2
DETERMINATION OF INFILTRATION/ INFLOW	3.3	3-59	1
General Consideration	3.3.1	3-59	2
Determination of I/I Using Wastewater Flow Data	3.3.2	3-61	1
Determination of I/I by Direct Flow Measurement	3.3.3	3-70	2
Adjustment of Flow Data	3.3.4	3-72	2
COST-EFFECTIVENESS ANALYSIS	3.4	3-73	2
Cost Estimate	3.4.2	3-74	2
Analysis Procedures	3.4.3	3-85	2
ESTABLISHMENT OF POSSIBLY EXCESSIVE OR NONEXCESSIVE I/I	3.5	3-89	1
SEWER SYSTEM EVALUATION SURVEY PROGRAM RECOMMENDATION	3.6	3-90	2
Program Recommendation	3.6.1	3-91	2
Cost Estimates	3.6.2	3-94	2
Project Schedule	3.6.3	3-94	2

TABLE 2-2

CHECK LIST FOR CONDUCTING SEWER SYSTEM EVALUATION SURVEY

Function	Subheading No.	Page No.	
PHYSICAL SURVEY	4.2	4-2	____
General	4.2.1	4-2	____
Aboveground Inspection	4.2.2	4-3	____
Flow Monitoring	4.2.3	4-3	____
Manhole and Sewer Inspection	4.2.4	4-4	____
Report	4.2.5	4-10	____
RAINFALL SIMULATION	4.3	4-10	____
General	4.3.1	4-10	____
Smoke Testing	4.3.2	4-12	____
Dyed Water Testing	4.3.3	4-15	____
Water Flood Test	4.3.4	4-18	____
PREPARATORY CLEANING	4.4	4-20	____
General	4.4.1	4-20	____
Equipment	4.4.2	4-20	____
Selection of Cleaning Equipment	4.4.3	4-24	____
INTERNAL INSPECTION	4.5	4-24	____
General	4.5.1	4-24	____
Inspection Techniques	4.5.2	4-25	____
SURVEY REPORT	4.6	4-32	____
General	4.6.1	4-32	____
Data Analysis	4.6.2	4-33	____
Cost-Effectiveness Analysis	4.6.3	4-35	____
Recommendation for Sewer System Rehabilitation	4.6.4	4-37	____

CHAPTER 3

INFILTRATION/INFLOW ANALYSIS

3.1 INTRODUCTION

An Infiltration/Inflow (I/I) Analysis is an engineering analysis demonstrating possibly excessive or nonexcessive infiltration/inflow in a sewer system or portions thereof. The principal purpose of the Infiltration/Inflow Analysis is to establish this expediently and yet thoroughly.

Generally, the I/I Analysis will be incorporated in the Project Facilities Planning Report or area wide waste management plans. There will be instances, however, when the I/I Analysis Reports will be separate documents. For example, Analysis Reports that are prepared on projects begun prior to PL 92-500 will generally be separate documents. Also, some planning documents will be voluminous; therefore, the I/I Analysis portion will be a separate document merely for convenience.

The I/I Analysis Reports will generally be in one of two forms:

- Sewer systems that have reliable data available which will conclusively demonstrate nonexcessive or possibly excessive I/I, the data may be briefly summarized. The engineer preparing the report should display sufficient flow data and specific characteristics of the sewer system to enable a review engineer to properly assess the system and concur with the report. A cost-effectiveness analysis may or may not be needed to establish the existence or nonexistence of excessive I/I.

- Sewer systems that have limited data (including flow and sewer characteristics) available will generally require a more structured analysis report than the aforementioned circumstance. This report generally will include a cost-effectiveness analysis. The degree of investigative work required for this type of analysis will obviously depend on the specific sewer system. The main goals of this investigative work will be the following:

(1) To generate sufficient flow data and characteristics of the sewer system that will enable a sound engineering decision to be made on possibly excessive or nonexcessive I/I.

(2) To obtain realistic cost estimates for rehabilitation of sewers that may contain possibly excessive I/I and for the transport and treatment of extraneous water.

(3) Items (1) and (2) should enable the engineer, in the event of possibly excessive I/I, to scope in detail the work tasks for the next investigative Phase, the Sewer System Evaluation Survey.

The following subheadings are the most commonly utilized components of an I/I Analysis Report. The presentation of these components or subheadings does not imply that they must be included in every I/I Analysis. Quite the contrary is true and only those subheadings that need be utilized to generate the desired data should be considered. In addition, other techniques that the engineer may have developed or generally utilizes, and which may not be displayed here, are encouraged. It should be kept in mind that this handbook shows some of the techniques utilized by engineers and municipalities to accomplish specific tasks. There are other techniques available and others that will be developed that may be as effective or more effective for a specific sewer system than those presented hereinafter.

The I/I Analysis report should not reiterate the data that would normally be presented in the Facilities Planning report but merely display the pertinent minimum data necessary to make a sound judgment of nonexcessive or possibly excessive infiltration/inflow.

The methodology presented hereinafter, unless otherwise noted, is applicable to both combined and separate systems.

3.2 BACKGROUND INFORMATION

The first step in conducting an Infiltration/Inflow Analysis is to obtain all the pertinent information and data on the specific wastewater collection system and treatment works under investigation. Much of this information and data will normally be collected by the engineer as the first step in conducting Facilities Planning; thus, duplication of effort should be avoided.

The investigator should screen all the background information and only utilize minimum information necessary to make a judgment of nonexcessive or possibly excessive infiltration/ inflow. The first attempt at making this determination should follow the analysis of all the background information or data. If a reliable judgment cannot be made after this, additional work, such as flow measuring at key manholes in subsystems or pumping station flow monitoring, may be required.

3.2.1 Interview

Interviews may be one of the first steps in the study of infiltration/inflow in a sewer system. The purpose of conducting an interview is to gather as much information as possible from the people who are familiar with the system. Results from well performed interviews may save the engineer considerable field work and also give him a clear overview of some or all of the problems at the onset and provide him with guidance as the study progresses. In the final analysis, the results from the interviews may also be utilized, along with other findings, to make a proper judgment as to the seriousness of the infiltration/inflow problems in the study area, the major problem areas in the system, the percentage of the infiltration/inflow which can possibly be removed and the areas which may deserve further investigation. A spin-off effect of the interview is that it may help the municipality recognize its problems and develop a program to eliminate and/or prevent them.

3.2.1.a. Person to Perform the Interview

Because of their importance, interviews should be well planned and should be undertaken by an experienced person. In some instances, discussions with municipal engineers, public works directors and treatment plant and sewer superintendents should be conducted by experienced engineers. In other instances, such as discussions with plant operators and sewer line laborers, it may be advantageous to have an experienced technician to conduct the study.

3.2.1.b. Persons to be Interviewed

The persons who might be interviewed are those who know the sewer system and its related problems, and are familiar with the general conditions of the study area. They may include the following:

- Sewer maintenance personnel
- Sewage treatment plant operators
- Municipal engineers
- Municipal Officials
- Sewer Commissioners
- Consulting engineers
- Local contractors
- Home owners
- Industry representatives

Sewer maintenance personnel and treatment plant operators possess the first-hand knowledge of the sewer system and the sewage treatment facilities and are often the major information sources. Questions to ask this group of people could include the structure of the existing sewer system, the sewer maintenance program, the sewer construction practices and the observed problems in the sewer system and the sewered areas. Much of the same information could often be obtained from knowledgeable municipal sanitary engineers.

When necessary, both the retired and the present personnel may be interviewed. In many older systems, where adequate sewer ordinances were not previously available, changes of sewers, additions of cross connections between sanitary sewers and storm sewers, direct drainage of impounding areas to the sanitary sewer, etc. were often made without proper authorization and records are sometimes unavailable. Information of this sort can often be obtained from retired sewer maintenance personnel, retired treatment plant operators, or retired municipal engineers.

Local construction contractors may provide information on the soil and groundwater conditions in the study area, and the practice of installing roof leaders, cellar, yard, area and foundation drains, during the construction of local homes and public buildings.

Home owners may indicate areas that flood during heavy rainfalls, homes with sewage backup problems and other obvious problems related to the sewer system.

The major industrial plants in the area could be contacted to gather the information on their water usage, wastewater discharge practices, plant operation schedule, etc. which would be useful for the estimation of normal sewage flows and for the planning of the flow monitoring schedules to be needed later.

The Municipal Officials, the City Engineers or the Sewer Commissioners may provide information on the jurisdictional and legal aspects of the sewer system and help solve problems in the areas where more than one municipality is involved. Questions such as the content and effectiveness of the sewer ordinances and the solutions to the problems of inflow sources on private properties, could be discussed with the responsible officials in the local government. The consulting engineers retained in the past by the municipality to provide planning or design work on the sewerage system in the study area may also have a general knowledge of the sewer system and its related problems and may also be contacted.

The number of persons to interview depends on the completeness of the information obtainable from the people already interviewed. The interviews can be conducted either individually or collectively.

3.2.1.c Content of the Interview

The interview should cover a broad spectrum of subjects including but not limited to the following:

- The sanitary sewer system
- The storm sewer system
- The existing sewer maintenance program (including cleaning, inspection and rehabilitation)
- The problem areas in the sewer system
- The geological and geographical conditions in the sewered areas
- The population and water consumption data
- The industrial wastewater flows
- The legal and jurisdictional aspects of the sewer system

A typical interview form is presented in Table 3-1. This form is merely a guide and each engineer should develop a form specific to the system under study.

TABLE 3-1 INFILTRATION/INFLOW ANALYSIS

INTERVIEW FORM

(Note: This form is intended as a general guide only. Engineers should develop their own forms for specific systems under study).

Project:______________________________ Project No.________

Interview Date:_______________________

Interviewee: Name_____________________________

Title_____________________________

Organization_______________________

Address___________________________

Length of affiliation with the organization or living in this area ____ years.

Interviewer:__________________________________

I. SEWER SYSTEM

A. Type of System: Separated____; Combined ____;

Partially combined with about ____% of the system being combined.

B. General Comments about the Sewer System:______________

____

C. Inventory of Sewer System:

1. Sanitary Sewer System (or combined system)

a. Availability of Sewer maps, construction plans and contract documents:______________________

____

b. Age of sewers:________________________________

c. Sizes of sewers:_____________________________

TABLE 3-1 (Continued)

d. Total length of gravity sewers:____________

e. Total length of force mains:______________

f. Number and locations of treatment facilities:

____

g. Type of treatment process in the treatment facilities:

____

h. Number and locations of pumping stations:

____

i. Number and locations of overflow points:

____

j. Number and locations of bypassing points:

____

k. Number and locations of river crossings:

____

2. Storm Sewers

a. Indicate areas where cross connections between sanitary sewers and storm sewers exist:

____

b. Indicate locations where sanitary sewers and storm sewers are constructed in same trenches or in close proximity:

____

____

D. Sewer System Maintenance Program

1. Maintenance Schedule:________________________

2. Work normally performed:______________________

TABLE 3-1 (Continued)

3. Equipment available: ____________________________

4. Personnel available: ____________________________

5. Availability of maintenance records: ____________

6. Indicate areas where sewers require frequent cleaning:

____

7. Types of deposits encountered: _________________

8. Cleaning methods used: _________________________

9. Sections of sewers T V inspected: ______________

10. Indicate sections of pipes that have been repaired and dates of repairing:

____

11. Methods and materials used for repairing: _______

____

12. Difficulties involved during maintenance: _______

____

E. Sewer Construction

1. General comments on the workmanship of sewer construction for this system

____

____

2. Sewers

a. Sewer materials: ___________________________

b. Joint types: ______________________________

c. Pipe depths: ______________________________

d. Bedding materials: __________________________

e. Packing materials: __________________________

3. Manholes

a. Manhole construction materials: ____________

b. Types of manhole covers installed: _________

TABLE 3-1 (Continued)

c. Indicate locations where sewer lines change in direction and grade without installing manholes:

____

d. Indicate locations of cleanouts in sewer lines:

____

e. The average distance between manholes is: _____ ft.

4. House service connections

a. General comments on construction methods used:

____

b. Sizes and materials of pipes installed: ___________

____

c. Indicate known areas where roof drains, areaway drains and foundation drains and cellar sump pumps are discharged to sanitary sewers:

____

____

____

d. Indicate areas where open joints and/or joint defects exist:

____

____

F. Observed Problem Areas

1. Sewers

a. Indicate locations where the following pipe defects or problems were observed:

(1) Cracks: ______________________________

(2) Collapse: ____________________________

(3) Offset joints: ________________________

(4) Misalignment (horizontal or vertical):

____

TABLE 3-1 (Continued)

(5) Root penetration: ______________________

(6) Heavy deposition: ______________________

(7) Vandalism: ______________________

(8) Other Observations: ______________________

b. Indicate sections of sewers which surcharge and state possible causes and consequences:

(1) Location: ______________________

(2) Causes: ______________________

(3) Consequences: ______________________

c. Indicate areas where emergency manhole pumpings were required during heavy rainfalls and state the dates, the rate of pumping and the intensities and durations of rainfall causing the overflows:

(1) Location: ______________________

(2) Dates: ______________________

(3) Pumping rates: ______________________

(4) Rainfall intensity: ______________________

(5) Rainfall duration: ______________________

d. Indicate locations where basement backups due to sewer surcharge were reported:

____

____

e. Indicate locations where direct inflows of surface drainage waters to the sanitary sewers were observed:

____

____

____

TABLE 3-1 (Continued)

f. Indicate locations where water mains were reportedly broken:

____

g. Indicate sections of storm sewers which were found broken and are adjacent to sanitary sewers:

____

2. Manholes

Indicate locations where the following manhole defects or problems were observed:

a. Cracks: ____________________________

b. Leaking:

(1) Location: ________________________

(2) Dates: ________________________

(3) Weather: ________________________

(4) Magnitudes: ________________________

c. Depressed manholes: ________________________

d. Located in low-lying areas: ____________________

e. Receiving surface runoffs: ____________________

f. Perforated or broken covers: ____________________

g. Covers missing: ________________________

h. Heavy deposition: ________________________

i. Inaccessible manholes: ____________________

j. Other Observations: ________________________

3. Overflows and Bypasses

a. Indicate locations where dry weather overflows occur and estimate magnitudes of overflows:

(1) Locations: ________________________

(2) Magnitude: ________________________

TABLE 3-1 (Continued)

b. Indicate locations, dates and magnitude of wet weather overflows and state the corresponding intensities and durations of rainfalls:

(1) Location: ____________________

(2) Date: ____________________

(3) Magnitude: ____________________

(4) Rainfall intensity and duration: ________

____

c. Indicate locations and magnitudes of bypasses and methods of activation:

(1) Location: ____________________

(2) Magnitude: ____________________

(3) Method of activation: ____________________

d. Indicate locations where overflows from catch basins in storm sewers occurred:

____

II. BACKGROUND INFORMATION ABOUT SEWERED AREAS

A. Geological and Geographical Information

1. Indicate types of soils in different areas: ________

____

____

2. Locate areas which were swampy, lowland areas prior to filling for development:

____

____

3. Locate potential problem areas such as waterways, creek crossings, and natural ponding areas:

____

TABLE 3-1 (Continued)

4. Indicate groundwater levels in different sewered areas during:
    a. Dry season: ______________________________
    b. Wet season: ______________________________
5. Indicate water level fluctuations in the streams:

    ____

6. Indicate sewered areas that were flooded previously:
    a. Location: ______________________________
    b. Date: ______________________________
    c. Rainfall intensity and duration: ____________
7. Indicate locations of wells that can be used as groundwater gaging points:

    ____

B. Population
1. Present population: ______________________________
2. Sewered population: ______________________________
3. Locate the following areas:
    a. Most densely populated: ____________________
    b. Least densely populated: ____________________
    c. Trailer parks: ______________________________
    d. Commercial areas: ___________________________
    e. Industrial areas: ___________________________

C. Water Consumption
1. Total water consumption rate: ____________________
2. Per capita water consumption rate: _______________
3. Industrial water sources and consumption rates:
    a. Sources: ______________________________
    b. Consumption rates: ______________________

TABLE 3-1 (Continued)

D. Legal Aspects

1. Availability of a sewer ordinance: ______________

E. Industrial

1. Industrial plant operation schedule: ____________
2. Industrial water sources: ______________________
3. Industrial water consumption rate: ______________
4. Industrial wastewater discharge rate and schedule:

____

Before the interview, maps of the study area, if available, should be studied to get familiarized with the area. During the interview, important information could also be marked on the maps to supplement the descriptions recorded in the interview form.

Before an interview, the purpose, nature and significance of the study should be explained to the persons being interviewed to avoid any misunderstanding and to obtain full cooperation. Good public relations should be practiced at all times.

Pertinent existing records, such as treatment plant records, sewer maps, sewer maintenance records, including information of previous cleaning, TV inspection and rehabilitation, sewer system construction, contract documents, water consumption records, sewer ordinance, discharge permit information, etc., should be collected during the interviews to facilitate further study.

3.2.1.d. Treatment of the Interview Results

After the interviews, tables could be constructed to summarize the findings, and problem areas could be plotted on the maps for easy identification. Discrepancies among interviewees and/or between the interview results and the existing records should be evaluated. Some spot checking should be made to substantiate the interview results. From an analysis of the collected information, a plan of action can now be made to gather more needed data for the completion of the infiltration/inflow analysis.

3.2.2 Sewer Map Analysis

Maps of the existing sanitary and storm sewer systems may be necessary in order to conduct an I/I Analysis particularly when the flow data are limited and flow monitoring at key manholes is desirable. In systems where sewer maps are available, it may be advisable to verify some of the critical points in the field before total acceptance. Sewer maps should also be updated to include new sewer extensions, sewer line changes, buried manholes, and any other pertinent data.

In systems where sewer maps are not available or incomplete, efforts should be made to produce adequate maps for the study. (The methods and equipment used for sewer mapping are discussed in the following subsection.) Generally, the costs for sewer map preparations suitable for Infiltration/Inflow Analyses and Evaluation Surveys are fundable costs, to the extent necessary for the study.

All available information need not be included in the sewer maps for an analysis report. The following basic items are generally required:

- All sanitary and combined sewers;
- Size of sewers and direction of flows;
- Locations of treatment facilities, pumping stations, flow measurement manholes, overflow and bypass points and river crossings;
- Storm sewers in the vicinity of sanitary sewers and those crossing or constructed in the same trenches as the sanitary sewers.

All manholes and their inverts need not be shown for an analysis report. In some instances, results from interviews or preliminary analysis may indicate that no infiltration/inflow problems exist in certain areas of the system; sewer layouts for such areas are not required if not available.

The scale of sewer maps may vary depending on the size of the system. In general, a scale of 1 inch = 400 feet (or, 1/4,800) is satisfactory. For larger areas, the sewer system may have to be broken down into several smaller systems, and a separate map may be prepared for each smaller system. However, a system flow diagram should be prepared to show the inter-relationships among all the systems.

3.2.2.a Map Preparation

A street map is generally useful for the preparation of a sewer map. In cases where street maps are not available, a schematic layout of the sewer system may be suitable, or an aerial photograph of the area may be taken and a map developed. After the map is prepared, the existing sewers should then be laid out on it.

Sewer location and direction of flow can be identified by a number of methods. The following methods are common:

- Dye tracer
- Floats
- Smoke
- Metal detectors
- Interview

These methods can be used to develop a complete sewer map, to complete a partially completed sewer map, or to check the existing sewer map for accuracy. The selection of a particular method or a combination of several methods for a given job will depend on the field situation and should be judged individually.

3.2.2.a (1) Dye Tracer - The dye tracer method involves the addition of a water-soluble dye to a manhole and determining the paths of flow by observing the dye at the downstream manholes and outlets. A sewer map can be developed by plotting all the flow paths determined in this manner.

Several types of dyes are available for sewer tracing, including fluorescein, Rhodamine, Rhodamine W, Rhodamine WT, methyl orange, nigrosine, etc. The characteristics of some of these dyes are shown in Table 3-2. Proper selection of a suitable dye and the respective feed concentration suitable for visible or instrument observation after dilution in the sewers is essential for successful application.

Powdered dyes are usually dissolved in water to make concentrated solutions for easy handling. The solution concentration and the quantity to apply depend on the magnitude of sewage flow.

3.2.2.a (2) Floats - Floats, such as wood chips, cork floats, stoppered bottles, oranges, etc., can also be used to determine the flow path in a sewer. However, in heavily deposited or obstructed sewers, this method may not be feasible. The floats should be specially marked to distinguish them from similar objects in the sewage.

3.2.2.a (3) Smoke - Smoke produced from a smoke bomb in a manhole and blown by an air blower will show up in adjacent manholes if the sewer is not flowing full or if there are no water traps in the sewer section being investigated. One added advantage of this tracing technique is that, in certain cases some infiltration/inflow sources may also be detected.

3.2.2.a (4) Metal Detectors - Commercially available metal detectors can be used to locate buried metal sewers and manholes with metal covers. Because of possible interferences from other underground utility pipes, the detectors should be used by an experienced operator.

TABLE 3-2

PROPERTIES OF COMMONLY USED TRACER DYES* [12]

Dye color, formula and common name	Manufacturer's brand name	Available forms	Specific Gravity of Solutions	Remarks
Basic Violet 10 $C_{28}H_{31}N_2O_3Cl$ Rhodamine B	Rhodamine B[1] Extra	Powder		Strong points: Very high detectibility, moderate cost. Weak points: Fair diffusivity, moderate sorptive tendency, moderate rate of photochemical decay, high acidity of solutions given.
	Rhodamine B[1]	40 percent solution (by wt.)	1.12	
	Rhodamine BA[1]	40 percent solution 30 percent solution (by wt.)	1.03 1.03	
	Rhodamine WT[1]	20 percent solution	1.19	Strong points: High detectibility, low sorptive tendency, good diffusivity, low acidity. Weak points: High cost, heavy.
Acid Red 52 $C_{27}H_{29}N_2O_4S_2Na$	Sulpho Rhodamine B[2] Fluoro$_3$Brilliant Pink[3]	Powder		Strong points: Fairly high detectibility, low sorptive tendency, good diffusivity, low decay rate, fairly stable at pH extremes. Weak points: high cost
Acid Yellow 73 $C_{20}H_{12}O_5$ Fluorescein	Fluorescein	Powder		Strong points: Inexpensive, low sorptive tendency, low temperature effect. Weak points: Very high photochemical decay rates; high potential interference by background.

*Note: Before using, the health effects of these dyes should be carefully considered. Dyes with carcinogenic potentials should be avoided.

[1] Product of E. I. DuPont de Nemours Co., Wilmington, Del.

[2] Product of General Aniline and Film Corp., New York, N.Y.

[3] Product of Keystone Aniline and Chemical Co., Chicago, Ill.

3.2.2.a (5) Interview - Interviewing people having a first-hand knowledge of the sewer system is also one way to construct a sewer map. Usually, the personnel in the local sewer maintenance department have a better knowledge of the sewer system than anybody else and should be contacted first. To avoid possible error, some limited field work should be done using the aforementioned techniques to substantiate the interview results.

3.2.2.b Map Study

Once the sewer map is prepared, it can be used as a valuable tool during the study. The following information pertinent to infiltration/inflow can be indicated or overlayed on the sewer maps:

- Topography of the study area
- Soil formation
- Groundwater distribution
- Sewer age
- Known or potential problem areas such as areas subject to floodings during heavy rainfalls, surcharged sewers, overflowing manholes, overloaded pumping stations, houses with sewer back-up problems, obvious inflow sources, existing and historical swampy areas, etc.

A careful inspection of the sewer maps with this added information, adequately keyed, may enable one to gain valuable insights into the infiltration/inflow problems of the area. For example:

(1) Storm sewers crossing, parallel to, or in the same trenches as the sanitary sewers may be potential infiltration and inflow sources: i.e. storm water may exfiltrate from the storm sewers and infiltrate through defective joints, etc. to the adjacent sanitary sewers; some relief cross-connections between these two types of sewers may have been made in the past to allow the storm sewers to overflow to the sanitary sewers.

(2) Sewers constructed near rivers, streams, ditch sections, ponding areas and swamps may present serious infiltration/inflow problems due to groundwater seepage or direct drainage.

(3) Sewers constructed in poor soils may be subjected to settlement resulting in open joints and/or pipe cracking.

(4) Low-lying areas may be subjected to flooding during heavy rainfalls. Manholes with perforated covers in such areas may present serious inflow problems.

(5) Older sewers may present more structural defects. Sewers with oakum-bituminous, oakum-mortar or cement-mortar joints may present more serious infiltration problems than sewers with gasket joints.

(6) Sewers constructed above seasonal groundwater level may present little infiltration problems.

(7) Serious infiltration/inflow problems may exist in areas where there are one or more of the following conditions:

   (a) Sewers being surcharged

   (b) Manholes overflowing

   (c) Pumping stations overloaded

   (d) Houses having sewage back-up problems

Based on this analysis, an engineering judgment can be made as to:

(1) What the degree of the problems might be in different areas; and

(2) If more detailed investigation should be made, where to concentrate the efforts.

3.2.3 Inventory of Existing Sewer System

An inventory of the existing sewer system will enable both the investigator and the reader to have a general understanding of the nature of the system. The following items may be summarized and included in the report:

- Type of sewer system, i.e., separate or combined system or combination;
- Age of sewers;
- Sizes and lengths of sewer pipes;
- Pipe materials;
- Types of joints and joint materials;

- Numbers of manholes and catch basins;
- Maximum, minimum and average depth of sewers;
- Bedding and backfill materials;
- Construction techniques;
- Types and numbers of overflows and bypasses;
- Physical conditions of the sewers.

This information could be obtained from reviewing the sewer maps, as-built sewer construction plans and specifications, etc. Some information is also obtainable from interviews. Typical data sheets for recording the above information (except the last item) are shown in Table 3-3.

3.2.3.a Type of Sewer System

The type of the sewer system should be known because the nature of the infiltration/inflow problem of a separate sanitary sewer system may be different from that of a combined sewer system. In a separate sanitary system, both the infiltration and the inflow problems should be investigated, while in a combined system, generally only the infiltration problem needs to be stressed. Combined sewers are usually designed to remove the rainfall-induced flows in an area as well as the wastewater discharges from various sources. By definition, most of the inflow problems are rainfall-related and should not have any impact on the combined system. However, inflow sources not directly related to rainfall, such as industrial cooling water discharges, drains from springs and swampy areas, etc., should be identified and studied in a combined system as well as in a separate system.

The requirements for handling overflows in separate sewer systems are also different from those in combined sewer systems. Overflows and bypassing should be eliminated from separate sanitary systems, but not necessarily from combined systems. Overflows or bypasses from combined sewers may or may not need some degree of treatment before discharging to the receiving waters or land disposal, depending on the requirements in the National Pollution Discharge Elimination System (NPDES) permit. This will affect the treatment costs in the final cost-effectiveness analysis.

TABLE 3-3

TYPICAL DATA SHEETS FOR THE INVENTORY OF EXISTING SEWER SYSTEM

I. SANITARY GRAVITY SEWERS OR COMBINED SEWERS

Pipe Age	Size In.	Length, Ft	Pipe Materials	Joint Type & Material	No. of MH's	Sewer Depth, Ft	Bedding Material	Backfill Material
Sub-Total								

II. SANITARY FORCE MAIN

Pipe Age	Size, In.	Length, In.	Material
Sub-Total			

III. OVERFLOWS

No.	Location	Description	Frequency of Over-flow, Times/yr	Over-flow Rate, gpm	Probable Causes of Overflow	Dis-charge Point

IV. BYPASSES

No.	Location	Description	Frequency of Flow Bypass, Times/yr	Bypass Flow Rate, gpm	Condition Required for By-passing	Dis-charge point

TABLE 3-3 (Continued)

V. PUMPING STATIONS

No.	Location	Type of Pumps	Pump Rate, gpm	Average Daily Flow, gpd	
				Low Groundwater	High Groundwater

3.2.3.b Age of Sewers

The age of a sewer system may partially reflect its general conditions and the degree of the potential infiltration/inflow problems. Buried sewers are constantly subjected to different adverse environmental conditions and deteriorate with time. Sewers constructed in poor soils may settle and create offset joints or cracks. Sewer pipes and pipe joints may be attacked by the chemicals in the groundwater, such as sulfates and organic acids. Metal sewers may be electrolytically corroded by the stray currents in the groundwater. Sewer joints may be penetrated by plant roots. Increased surface loadings may cause crushing or cracks in gradually deteriorated sewers. Such factors render the older sewers more vulnerable to infiltration than the newer ones. In addition, one can expect to find more cross-connections between sanitary sewers and storm sewers and more direct inflow sources in older sewer systems than in relatively new systems because most older systems were constructed when there were no adequate sewer ordinances, and without thorough inspection.

3.2.3.c Other Appurtenances

Bypasses and overflows should be identified and observed in the field. The specific construction of the overflows and bypasses should be determined and the operation of each should be understood. Information regarding the activation of overflows and bypasses should be established either from past observations or throughout the I/I Analysis and/or Evaluation Survey.

Pumping stations should be identified and design and operational characteristics of these should be documented.

3.2.4 Geographic and Geological Data

A general knowledge of the geographic and geological conditions of the sewered area may enable the engineer to better understand the infiltration/inflow problems in the area. Provided with sufficient data, the engineer can pinpoint some potential problem areas and plan possible corrective actions. As will be discussed in Chapter 5, for sewer rehabilitation work, the type of the soils and the groundwater conditions around the sewers also dictate the type of the chemical grout to be used.

3.2.4.a. Topography

3.2.4.a (1) Importance of Topographic Data - The topography of an area reveals the extent and direction of surface drainage, the locations of low-lying areas and the areas where sewers are close to or crossing rivers, streams and/or swampy areas.

Low-lying areas are subjected to possible floodings during heavy rainfalls and the extent of the surface drainage determines the seriousness of the flooding problem. In such areas, a considerable amount of surface runoff may enter the sewer system through exposed open joints, perforated sewer manhole covers, structurally defective manholes, abandoned house connections, etc. Prolonged rainfall may also saturate the soils and increase the possibility of rainfall-related infiltration through deteriorated pipes, pipe joints and/or manhole walls. Sewers constructed in the vicinity of or crossing rivers, streams or swampy areas may have a higher possibility of being surrounded by saturated soils than those constructed in the other areas and may present a greater infiltration/inflow problem than the sewers lying in areas farther away from the water sources.

3.2.4.a (2) Data Collection and Presentation - Topographic maps and aerial photographs may both provide sufficient information for topographic study. Topographic maps are generally available from the U.S. Geological Survey. Aerial photographs can be obtained from: (1) U.S. Department of Agriculture, Commodity Stabilization Program, (2) Local or County Planning Departments, (3) U.S. Corps of Engineers Offices, and (4) Private Photogrammetry and Mapping companies.

The topographic maps should be studied and analyzed by the engineer to locate areas of potential infiltration/inflow problems. The important findings from this study may be shown and discussed in the analysis report.

3.2.4.b Rainfall

3.2.4.b (1) Importance of Rainfall Data - Both infiltration and inflow are affected by rainfall. By definition, the amount of inflow to a sewer system is, mostly, directly related to rainfall. The direct relationships between rainfall and infiltration, on the other hand, are not so apparent. While most of the infiltration phenomena are caused by the seepage of the groundwater through defective pipes, pipe joints, connections, or manhole walls, rainfall during a high groundwater period indeed aggravates the infiltration problem. On the one hand, rainfall and/or the surface run-off may seek the cracks in the soil surrounding the manholes and leak through the deteriorated manhole walls to cause an infiltration problem. On the other hand, during a heavy rainfall, the rainwater may reach the groundwater by percolating through some highly permeable soils and cause a general increase of the groundwater level. This increases the total hydraulic head above the sewer pipes and causes more water to enter the pipes through defected joints, etc. In locations where the sewer pipes cut the underlain bedrock, the rainwater, after percolating through the overlying soils, may flow over the rock surface to the areas of lower elevations, generally in the sewer trench, and there cause an increased infiltration problem in the sewers.

During heavy rainfalls, another phenomenon may occur in the soil and increase the infiltration rate in the sewers. This is the case when a large ground surface is covered by impounded rainwater; as this large blanket of impounded water percolates through the soils underneath, it leaves little chance for the air in the soil to escape. Because of this, the air is subjected to increasing pressure. The pressure is transmitted to the groundwater above the sewer pipe and causes an increase in infiltration rate through defective pipe joints, etc.

Therefore, rainfall data are very important for the infiltration/inflow study. For adequate infiltration/inflow analysis, the following rainfall data are generally needed:

- Average annual rainfall;
- Daily rainfall for the wettest season in the most recent year;
- Hourly rainfall for some typical raining days.

3.2.4.b (2) Data Collection - Rainfall data are usually obtainable from the following sources:

- National Weather Services, local offices;
- Climatological data published by the National Weather Service;
- Airports;
- Universities;
- Military installations; and
- Sewage treatment plants.

When this information is not available or additional data are required, rainfall gauges may be installed at selected locations in the study area and the data gathered over some reasonable length of time. These data should then be compared with data from nearby sources.

3.2.4.c Soil

3.2.4.c. (1) Importance of Soil Data - Soil conditions in an area affect the magnitude of the infiltration/inflow problem in the sewer system in two ways, i.e.:

(a) The permeability of the soil determines the rate of movement of the groundwater through the soil and the subsequent effects on the sewers.

(b) The nature of the backfill and bedding materials surrounding the sewers affects the structural integrity of the sewers. All other conditions being equal, sewers constructed in permeable soils receive more infiltration than those constructed in less permeable soils. Relatively impermeable soils, such as clay, may also seal off pipe openings and reduce the quantities of infiltration that would otherwise enter these openings.

Sewers constructed on poor soils may be subjected to settlement, resulting in open joints or cracking of pipe. Unequal settlements of manholes and sewers in soils may result in open connections through broken pipes or joints. Elastic soils such as clay may subject the pipes to expansion and contraction, resulting in loose joints and/or broken pipes.

Thus a study of the soil conditions in the sewered area may be necessary to the understanding of some observed infiltration problems. It may also assist the engineer to locate areas where there are potential infiltration problems.

In the selection of chemical grouts for the sealing of sewer pipes and joints during sewer rehabilitation, the type of the soil surrounding the pipe is also one of the deciding factors.

3.2.4.c (2) Data Collection and Presentation - The information on soil distribution and soil characteristics in an area can be obtained from the following sources:

- Soil Conservation Service, U.S. Department of Agriculture;
- Boring logs in sewer construction contract documents;
- State Agriculture Extension Service;
- Local construction companies or contractors;
- Field investigation.

The Soil Conservation Service has published many soil maps with descriptions of soil characteristics to a depth of 5 feet. It has offices in most counties across the country. Boring logs contained in the sewer construction contract documents provide detailed information about the soils along the sewer construction route. The State Agriculture Extension Service may have collected data on the soil types and soil characteristics in the study area. Local construction companies and contractors may also have some information about the area's soil. For locations where no soil information is available, some field soil study may be needed. The study may include the conducting of test borings at key points and the interpretation of the collected soil samples. For complex and unusual cases, the soil samples should be interpreted by the soil scientists in the Soil Conservation Service, Agricultural Extension Service representatives, consulting soil scientists or agronomists.

The soil distribution and characteristics in the study area may be presented in the report. The significance of the effects of the soils on the integrity of the sewers and on the infiltration/inflow problems in the study area may also be discussed.

3.2.4.d Groundwater

3.2.4.d (1) Importance of Groundwater Information - By definition, most of the infiltration phenomena in sewers are groundwater-related. In areas where the groundwater level is lower than the sewer installation, infiltration may occur only during heavy storms. Both the level and the chemical characteristics of the groundwater affect the degree of infiltration in the sewers. Sewers in contact with groundwater may be attacked by the chemicals in the groundwater, such as sulfates and organic acids. Metal sewers may also be electrolytically corroded in the presence of groundwater. Once the openings in the sewers have occurred, under favorable soil conditions, the degree of infiltration is directly related to the level of the groundwater above the sewers.

Because of the influence of the groundwater on infiltration, the determination of infiltration in the sewer system should be based on a comparison of the sewage flow data collected in the high groundwater seasons versus those collected in the low groundwater seasons. To obtain realistic infiltration flow data in the Sewer System Evaluation Survey, the sewer line inspection should also be conducted during high groundwater seasons. Thus, accurate groundwater information of the study area is essential to the Infiltration/Inflow Analysis and the Sewer System Evaluation Survey. Groundwater monitoring will be needed if no data are available.

3.2.4.d (2) Data Collection and Presentation - General groundwater information may be obtainable from a number of sources such as:

- State Water Resources agencies;
- U.S. Geological Survey;
- Local or county water conservation districts;
- Groundwater users, including municipalities, water companies and individuals;
- Local construction companies or contractors.

To obtain more detailed groundwater information in the study area, field groundwater monitoring may have to be conducted. This can be accomplished by one or a combination of the following setups:

- Installation of groundwater gauges in sewer manholes at the crown of the pipe;
- Installation of groundwater gauges adjacent to the sewer pipes;
- Observation of the water levels in existing water wells;
- Observation of the water levels in specially dug water wells.

In a typical groundwater gauge installation in a manhole (Figure 3-1), the gauge is installed by inserting a pipe through the wall of the manhole at an elevation near the top of the lowest sewer and attaching a visible plastic viewing tube with calibrated scale to this pipe. The space between the pipe and the hole in the wall should be properly sealed to prevent leakage. The groundwater elevation outside the manhole is observed at the plastic pipe inside the manhole. Figure 3-2 shows a typical setup for a groundwater monitor in a specially dug or drilled water well. This installation would generally be made adjacent to the sewer pipe. The groundwater level can be determined by inserting a stick into the well casing and measuring the length of the unwetted portion of the stick after retrieval.

After the gauges or monitors are installed, they should be inspected regularly to obtain needed information. Continuous recording devices can also be installed if necessary. To determine seasonal groundwater variations, the monitoring may have to be extended to an entire year.

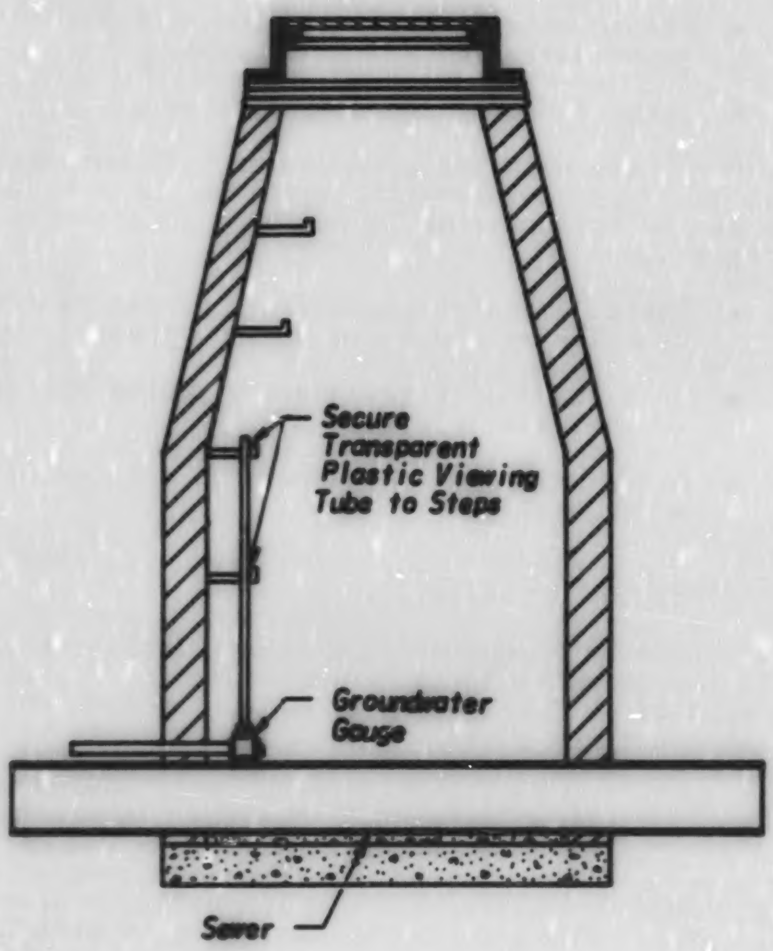
Secure
Transparent
Plastic Viewing
Tube to Steps
Groundwater
Gauge
Sewer

Figure 3-1. Typical Groundwater Gauge Installation in Manhole [1]

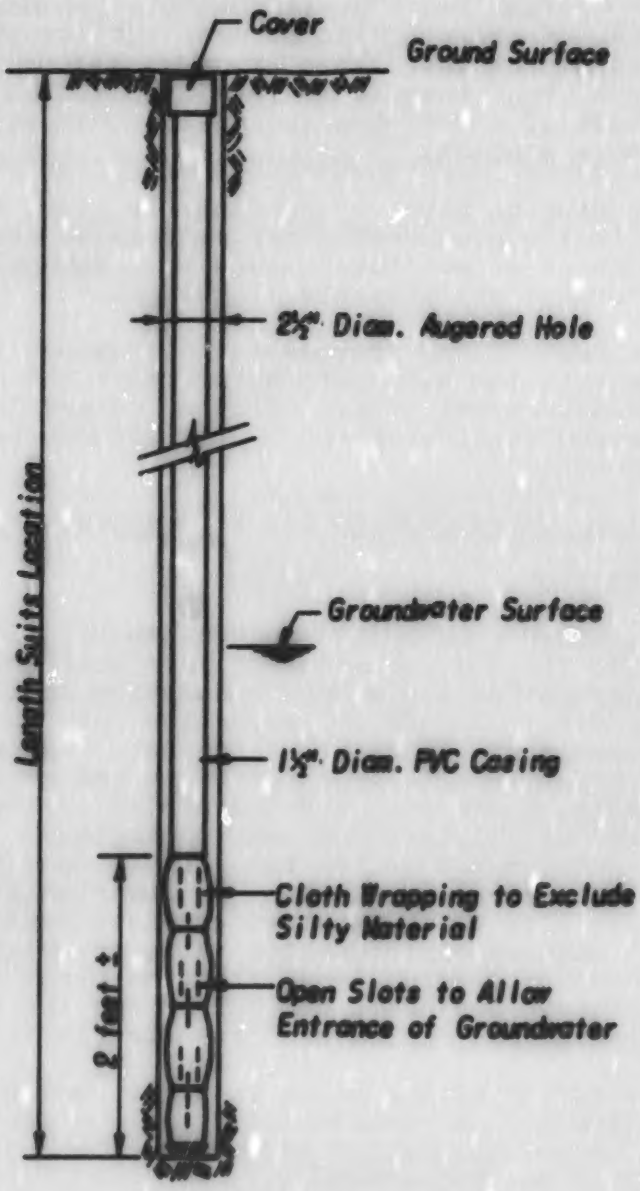
Cover
Ground Surface
2½" Diam. Augered Hole
Length Suits Location
Groundwater Surface
1½" Diam. PVC Casing
Cloth Wrapping to Exclude Silty Material
Open Slots to Allow Entrance of Groundwater
2 feet ±

Figure 3-2. Typical Groundwater Gauge Installation in Soil
(Courtesy of Dufresne-Henry Engineering Corp.)

The recorded data should always be reviewed and screened carefully before being used. Pumping water from nearby wells may cause a temporary draw down of the groundwater surface at the monitoring stations. Under such conditions, the recorded water levels do not represent the highest possible groundwater levels in the area under normal conditions. For infiltration studies, the highest groundwater levels are of major concern. Therefore, whenever possible, the groundwater levels should be recorded during the periods of a day when groundwater pumping in the study area is at a minimum.

Clogging of the gauging pipes or monitors by silt, clay or other minerals in the groundwater may also cause erroneous results. The gauges or monitors should be frequently checked to detect and correct any possible cloggings.

In the analysis report, the groundwater elevations should be presented along with the dates of measurements and monitor locations. The determination of infiltration and inflow should be made with proper considerations of the groundwater conditions in the study area.

3.2.5 Population, Water Consumption and Wastewater Flow Data

3.2.5.a Introduction

The population, water consumption and wastewater flow data are essential for the determination of infiltration and inflow. From population and water consumption data, the theoretical (or base) wastewater production rate in the study area can be determined. This production rate represents the quantity of wastewater normally expected in the sewer system, including domestic, commercial and industrial wastewater flows, but excluding all infiltration and inflow. Once the theoretical wastewater production rate is derived, the infiltration and inflow can be calculated by comparing it with the actual wastewater flow data. Wastewater flows over and above the theoretical wastewater production rate, correlated with weather and groundwater conditions, are considered as the infiltration/inflow. (Detailed procedures for the determination of infiltration and inflow are presented in Section 3.3.)

However, if the infiltration/inflow in a system can be determined by direct flow measurement, then the data for population and water consumption may not be the controlling factors in the I/I determination.

3.2.5.b Population

The population data need to be gathered only for the period in which records for water consumption, wastewater flow, groundwater and rainfall are all available. If these records were not available in the past and need to be generated during the study period, the population for the same period should then be known.

For the determination of infiltration and inflow, both the total population and the population serviced by the sewers (the sewered population) need to be known. In areas where there are seasonal fluctuations of populations, a detailed breakdown of the population according to season or month should be provided.

The population records are usually available in the U.S. Census Bureau, local government offices and sanitary districts. They may also be contained in previous engineering study reports. If no data are available, a house-to-house count may have to be done to determine the population.

3.2.5.c Water Consumption

The water consumption data should be obtained for the year(s) for which records for wastewater flow, groundwater and rainfall are all available. If these records are not available and need to be generated during the study period, the water consumption data for the current year or the immediate previous year should be obtained.

If metered water use data are available for all users in the study area, they should be collected and used for the estimation of wastewater production rate.

In communities where metered water use records are not available, the water supply data from all supply sources should be collected. Along with these, the portion of water consumption which is not expected to enter the sewer system, such as system losses, irrigation use, etc., should be estimated.

Water consumption records are usually obtainable from local water departments, private water companies, industrial plants and individual well users.

If no records are available, estimations can be made based on population and an inventory of the residential, commercial and industrial establishments in the study area using some typical water use rates.

3.2.5.d Wastewater Flow

Whenever possible, uninterrupted wastewater flow records covering a period of 1 to 2 years of the most recent years should be obtained for infiltration and inflow determination. Records which cover a period (or periods) shorter than this may also be sufficient if the period (or periods) includes all representative groundwater and rainfall conditions in the study area.

The flow records should cover the wastewater flows in the entire sewer system under study. In large sewer systems, flow records may have to be gathered from more than one treatment plant, pumping station or flow measurement station in the system. In addition, flow records for overflows, bypasses and emergency pumping should also be gathered, if available. Wastewater flow records, if available, can normally be obtained from sewage treatment plants, sanitary districts or sewer departments in local governments.

All records should be checked for accuracy before being used. The accuracy of the records can be determined by checking the accuracy of the instruments used for recording and totalizing the flows.

If no wastewater flow records are available, a flow measurement program should be initiated.

3.2.6 Flow Measurement

3.2.6.a Introduction

In the Infiltration/Inflow Analysis, flow measurements may be required for various reasons:

(1) For sewer systems which have sufficient existing flow data for the determination of infiltration/inflow, flow measurements may be needed for the following purposes:

  (a) To check the accuracy of the existing flow records;

  (b) To determine the infiltration/inflow in subdivided areas (the subsystems) to facilitate the determination of whether there is possibly excessive infiltration/inflow, through a cost-effectiveness analysis or other approaches; and

  (c) To determine the infiltration/inflow in subdivided areas so that subareas with no infiltration/inflow problems can be eliminated from further study and the planning of a Sewer System Evaluation Survey program can be accomplished.

(2) For systems which have no existing flow records or where data are insufficient or inaccurate, flow measurements are always needed for infiltration/inflow determinations and also for the aforementioned purposes.

Flows which need to be determined may include:

- Total wastewater flows, including domestic, commercial and industrial wastewaters and infiltration/inflow;
- Industrial wastewater flows;
- Bypasses;
- Overflows;
- Emergency pumpings; and
- Infiltration/inflow.

Along with flow measurements, groundwater and/or rainfall gaugings may also have to be performed in some instances.

Depending on the availability and adequacy of the existing flow data and the conditions in the sewer system and study area, either instantaneous flow measurement or continuous flow monitoring may have to be conducted.

3.2.6.b Planning of Flow Measurements

3.2.6.b (1) General - To obtain sufficient flow data for the analysis in as short a period of time as possible, proper planning cannot be overemphasized. The time suitable for flow measurement is generally limited because peak infiltration occurs only during high groundwater periods and peak inflow normally occurs only during heavy rainfall seasons. If high groundwater periods or heavy rainfall seasons are missed, the investigation may have to be postponed and the facilities planning may be delayed.

3.2.6.b (2) Timing of Flow Measurement - For accurate determination of infiltration/inflow, it is desirable to obtain continuous flow data over a period of an entire year; but, in most cases, extending the measurements to such a long period of time is not warranted. For adequate infiltration/inflow analysis, flow data for the periods covering high groundwater and rainfall conditions are usually all that are needed.

For the determination of peak infiltration, flows should be measured during the highest groundwater period of a year. To determine the peak inflow, flow data for the heavy rainfall periods should be obtained. To determine the total yearly infiltration/inflow, flows may also have to be measured during other typical groundwater conditions.

Continuous flow measurements are desirable. However, if the infiltration is to be directly measured, instantaneous flow measurement would be sufficient because the groundwater level is normally relatively stable over periods of several days. For direct inflow measurements, the flows should be monitored continuously throughout each rainfall period.

If infiltration is to be measured directly, the measurement should be performed in nonrainfall days, preferably at least 24 hours after a rainfall to minimize the direct influence of rainfall. To minimize the interferences caused by domestic, commercial and industrial flows, flow measurements should be performed during early morning hours, approximately from midnight to 6 a.m. To avoid possible errors caused by wastewater discharges during flow measurement, repeated flow measurements should be conducted in three consecutive nonrainfall days for each typical groundwater condition. Consideration must be given to industries that operate 24 hours per day, the living habits of the community and flow lag time in the pipes.

To minimize the interferences caused by domestic, commercial and industrial flows, direct inflow measurements should be performed during rainfall in the early morning hours.

To avoid surge flows, all pumpings in the sewer system should be temporarily stopped during flow measurement if instantaneous flow measurements are taken.

3.2.6.b (3) Division of Subsystems - For the determination of infiltration/inflow, flow measurement can normally be conducted at a single station to which the flow in the entire sewer system discharges, such as a sewage treatment plant or a pumping station.

However, in many sewer systems, there may be more than one treatment plant or pumping station, and they may not be interconnected. Under such circumstances, flow measurements have to be conducted in all plants or pumping stations.

To facilitate the cost-effectiveness analysis and to formulate a Sewer System Evaluation Survey program, a sewer system may be divided into a number of subsystems and the flows in each subsystem measured separately. The number of subsystems will vary from system to system, depending on the size, configuration and nature of the system and the complexity of the infiltration/inflow problems in the system. One or a combination of the following criteria can be used to divide the sewer system:

(a) Drainage Area - Sewer systems can be divided into subsystems according to the flow conditions in the sewers. A sewer map may reveal that the sewers are generally constructed in several major groups. The flows in the sewers of an area may converge to a single major point before reaching the next group of sewers downstream. The converging point can be a manhole or a pumping station. Under such conditions, it may be convenient to consider the sewers within the area upstream from the converging manhole or pumping station as a subsystem and measure the flows in this manhole or pumping station.

In systems that contain several treatment plants, the sewers contributing the flows to each plant can also be considered as a subsystem. The flow records in each plant can be used for infiltration/inflow determination. Additional flows, if needed, may also be measured at the treatment plants.

(b) Age or Type of Sewers - The sewers in a sewer system may have been constructed in different years. The degree of pipe deterioration varies in accordance with the age, the pipe and joint materials and the construction method used. Sewers constructed in different years may present different infiltration/inflow problems. To isolate the individual problem areas, sewer systems may also be divided into subsystems according to the age of the sewers and type of pipe.

(c) Groundwater and Soil Conditions - In a large study area, groundwater levels may vary in different regions. Some of the sewers may be constantly submerged in the groundwater; some may never be submerged; some others may be subjected to seasonal submergence; and in coastal areas, the sewers may be affected by a groundwater which fluctuates with the tide. Different groundwater conditions cause different types and degrees of infiltration/inflow problems in the sewers. Therefore, in some sewer systems, the subsystems can also be divided according to the groundwater conditions in the different regions of the study area.

Similarly, the soil conditions in the different regions of a study area may also vary widely and cause varied types and degrees of infiltration/inflow problems in the sewers. Subsystems may also be divided according to the soil conditions in the study area.

(d) Problem Areas - If, through interviews or other means, some major infiltration/inflow problem areas are suspected, these areas may also be singled out for detailed flow measurements and cost-effectiveness analysis.

3.2.6.b (4) Selection of Key Manholes - Before flow measurements are undertaken, the manholes used for measurements should be carefully selected. Manholes selected for flow measurement should be accessible and safe, suitable for installing flow measurement devices and in key locations. Careful selection of flow measurement manholes will save field work and provide sufficient essential flow information for further analysis.

Initially, the flow measurement manholes should be selected on the basis of an analysis of the sewer maps and the subsystems divided previously. Sufficient manholes should be chosen to adequately isolate the flows in each subsystem. It is not necessary to select one manhole for each subsystem. Similarly, more than one manhole may have to be selected in one subsystem to more precisely define the flows in some problem areas.

After the manholes are selected and before actual flow measurements are conducted it is advisable to locate the manholes in the field. This is important, especially when early morning flow measurements are planned. To make the job easy, personnel from the local sewer maintenance crew can be asked to help locate the manholes and provide background information about the manholes. In case a predetermined manhole cannot be found in the field due to various reasons, another key manhole should be selected and field-located.

When the flow measurement manholes are located, they should be opened and checked for accessibility and suitability for installing flow measurement devices. Items to check include:

- Safety precautions before entering the manhole;
- Size of the manhole opening and the inside diameter;
- Depth of the manhole;
- Workability inside the manhole;
- Stability of the manhole structure;
- Condition of manhole steps;

- Flow condition in the manhole;
- Amount of debris accumulation;
- Any additional pipe connections unrecorded in the sewer maps;
- Suitable location for installing flow measurement devices; and
- Traffic conditions during flow measurement periods.

A constantly surcharged manhole may not be suitable for flow measurement. All manholes found to be unsuitable for flow measurement should be replaced with other suitable manholes.

3.2.6.b (5) Other Measurements - Besides wastewater flow and infiltration/inflow measurements, other measurements which may have to be conducted are:

- Groundwater levels,
- Rainfall,
- Industrial wastewater flows,
- Bypasses,
- Overflows, and
- Emergency pumpings.

Flow measurements for the determination of infiltration should be accompanied by a measurement of the groundwater levels in the study area. Flow measurement for the determination of inflow should be accompanied by a measurement of the rainfall. When flows are continuously monitored, both groundwater and rainfall should be gauged simultaneously. The groundwater and rainfall information can be obtained either from existing gauging stations or through new setups.

Industrial wastewater flows may have to be measured for the determination of infiltration/inflow. If the infiltration and/or inflow are to be directly measured during the early morning hours, the wastewater flows from the night shifts of the industrial plants should be determined and deducted from the measured flows to derive the actual infiltration and/or inflow.

The flows from all bypasses, overflows and emergency pumpings which occur during flow measurement periods should be determined and added to the measured wastewater flow or infiltration/inflow so that true peak infiltration/inflow can be derived.

3.2.6.c Flow Measurement Techniques

When flow data must be generated, the flow measurements become a critical component of the I/I Analysis and/or Sewer System Evaluation Survey. It is necessary to use a sound approach and good flow measurement techniques to ensure reasonable results. The obtained results do not necessarily have to be as accurate as flow data obtained from a continuous flow monitor at the treatment plant. These measured flows will, however, be used in determining possibly excessive or nonexcessive I/I and thus some degree of accuracy should be employed.

To determine I/I, flow measurements may be taken at several locations. These locations will depend on the sewer system being investigated, the flow data that are available and the flow data that must be obtained. Flow measurements may be obtained at the following:

- Treatment plant influent,
- Treatment plant effluent,
- Pumping stations,
- Key manholes,
- Inflow sources that directly enter catch basins or manholes,
- Infiltration sources that directly enter manholes,
- Industrial waste sources, and
- Overflows and bypasses.

Other locations and sources of I/I may be measured in a particular sewer system. There are a variety of methods and equipment available for flow measurement in sewers. The selection of the proper method or equipment will depend on the cost, source to be measured, accessibility, manpower availability, degree of precision and type of data required. In the following subsections, a few of the most commonly used methods and equipment will be presented. The general format which will be employed will be as follows:

- Description of the method,
- Equipment available,
- Installation instructions, and
- Advantages and disadvantages.

3.2.6.c (1) Depth Measurement (Manual) -

- Method - This method involves obtaining an instantaneous depth of flow measurement in sewer pipes. In addition, a mean velocity of flow must be obtained in order to utilize the flow formula, $Q = AV$. The mean velocity may be obtained theoretically by use of the Kutter formula or the more simplified Manning equation, $V = \frac{1.486}{n} R^{2/3} S^{1/2}$. The velocity may also be determined by actual measurement with a velocity meter or by time-distance measurements using dye or floating objects.

- Equipment - Staff gauges marked to the nearest 0.01 ft or 1/8-inch would be suitable for depth measurements.

- Installation - In manholes that are relatively clean and accessible, the staff gauge may be inserted into the invert of the manhole channel and the depth of flow measured. The depth of sediment in the pipe should be noted and the depth of flow corrected accordingly.

  Some manholes may not be accessible. In these instances, depth of flow may be obtained by utilizing a stadia rod. An initial reading may be taken by placing the rod on the manhole channel invert and noting a reading on the rod with respect to a reference such as the manhole frame. A second reading can then be taken by raising the rod to the channel water surface and obtain a reading from the same reference. The difference in the two readings will be the depth of flow.

- Advantages -

  (1) Inexpensive
  (2) Rapid results
  (3) Ease of operation

- Disadvantages -

  (1) Instantaneous result that may not be representative

(2) Determination of mean velocity is critical
(3) Cannot be used in surcharged sewers
(4) Low degree of accuracy

3.2.6.c (2) Depth Measurement (Instrument) -

- Method - This method involves obtaining continuous depth-of-flow measurements in sewer pipes by various depth measuring and recording devices. In order to determine flow, the mean velocity must be established as described in the preceding section.

- Equipment -

  (1) Float-operated device which rides on the surface of liquid and transmits a signal to a receiver which records the relative depth or percentage of flow.

  (2) Pressure-differential depth or percentage-of-flow recorders which bubble air at a regulated rate through a tube which is secured to the invert of the sewer pipe or channel. The depth of flow above the bubble tube will cause a back pressure and thus the differential pressure can produce a signal which will be proportional to the depth of flow.

  (3) Sensing devices which continuously travel up and down and sense the water surface.

  (4) Ultrasonic sensing devices which utilize high frequency sound to sense the water surface.

  (5) A low pressure transducer installed in the invert of the sewer pipe which measures height (pressure) of flow and transmits a signal proportional to the depth of flow.

- Installation - Generally, the devices are installed in manholes and the floats or sensing devices are placed in or near the liquid. The specific installation of the various types of devices should be in accordance with the manufacturer's recommendations.

- Advantages -

  (1) Provides continuous recording
  (2) Provides a record of results
  (3) Generally accurate

- **Disadvantages** -

  (1) Relatively high capital cost
  (2) Routine maintenance required
  (3) Danger of theft and/or vandalism
  (4) Danger of exposure to adverse conditions

3.2.6.c (3) Weirs and Flumes

- Method - This method involves the observation or recording of depth of flow over a specific weir or through a flume. Weir or flume formulas or tables are utilized to determine the flow.

- Equipment - For flow measurements in sewer pipes, various V-notch weirs can be utilized. Commonly used V-notch weirs are 22-1/2°, 30°, 45°, 60° and 90°. In addition, rectangular and trapezoidal weirs may be used. Portable flumes are also available.

- Installation - When installing weirs and flumes, it is important to ensure that a good seal is made between the device and the pipe or channel. Sponge rubber or sand bags may be used for sealing purposes. The weirs and flumes should also be installed level.

- Advantages -

  (1) Low costs
  (2) Direct flow reading
  (3) Many designs available for flexibility
  (4) Generally accurate

- Disadvantages -

  (1) Must be installed in the sewer or channel
  (2) Cannot be used for sewers flowing full or surcharged
  (3) Weirs not recommended for fast flowing sewers
  (4) Instantaneous result

3.2.6.c (4) Timed Volume -

- Method - This method is used to determine flow rates from leaking manhole walls, wet well walls and accessible point sources of inflow. The method involves the use of a vessel of known volume; the time to fill this vessel is measured with a stop watch or watch.

- Equipment - One-, two- or five-gallon plastic pails are suitable for measurement of small streams. Larger vessels such as 55-gallon drums may be used but are cumbersome to handle. A stop watch or a watch with a sweep second hand is suitable for monitoring time.

- Installation - The equipment used for this method of flow determination is generally portable and no specific installation is required. When making the flow determination, the entire stream should be measured and the measurement repeated to ensure accuracy.

- Advantages -

  (1) Accurate
  (2) Inexpensive
  (3) No specific expertise required

- Disadvantages -

  (1) Generally cannot be used for flow in sewer pipes
  (2) Not adequate for high-velocity flows

3.2.6.c (5) Pumping Rates -

- Method - This method of flow measurement uses pump design curves and the pumping time. In addition, some pump stations have flow recorders which facilitate the gathering of flow data. For ejector stations, the number of times the system ejects may be counted; and coupling this with the volume per discharge, one can determine the flow.

- Advantages -

  (1) Extra flow-measuring equipment not generally necessary

3.2.6.c (6) Dye-Dilution Method -

- Method - The dye-dilution method is a simple and quick method for the determination of the flows in the sewers. The flow measurement can be conducted above ground; no manhole-entering is necessary. Using this method, flows can be measured even if the sewers are running full or surcharged. The method is normally used to measure the instantaneous flow rates in sewers. However, with some added equipment, continuous flow monitoring is also possible.

Basically, the method involves the following procedure:

(1) Feed a fluorescent dye at a constant rate to an upstream manhole.

(2) Collect the water samples from the sewers in the downstream manholes.

(3) Measure the dye concentrations in the collected samples with a fluorometer.

(4) Calculate the rate of sewage flow in each sewer section using the following formula:

$$Q_f = Q_1 \frac{C_1}{C_f} \qquad (3\text{-}1)$$

where:

Q_f = the flow rate in the sewer;

C_f = the dye concentration in the sewage collected at the downstream manhole;

Q_1 = the dye feed rate;

C_1 = the dye concentration in the feed tank.

- Materials - Three types of fluorescent dyes have been used extensively as water tracers: Rhodamine B, Rhodamine WT, and Fluorescein (Table 3-2). For accurate flow measurements in sewers, a dye which has low sorptive tendency with the solids in the sewage should always be used. The fluorescence of the rhodamine dyes is not stable outside of the pH range of 5-10. Most dyes undergo photochemical decay in the sunlight. Therefore, the samples should be stored in the dark and analyzed as soon as possible after collection. The fluorescence of the dyes is also affected by temperature. During sample analysis, if the temperature of the sample is different than the room temperature, a correction factor should be applied to the measured concentrations. (The temperature correction curve for Rhodamine B and Rhodamine WT are shown in Figure 3-3. The temperature effect of Fluorescein is small and, normally, need not be corrected.)

- Installation - Although commercial solution feeders are available, a simple homemade constant-head solution feeder is usually sufficient for feeding

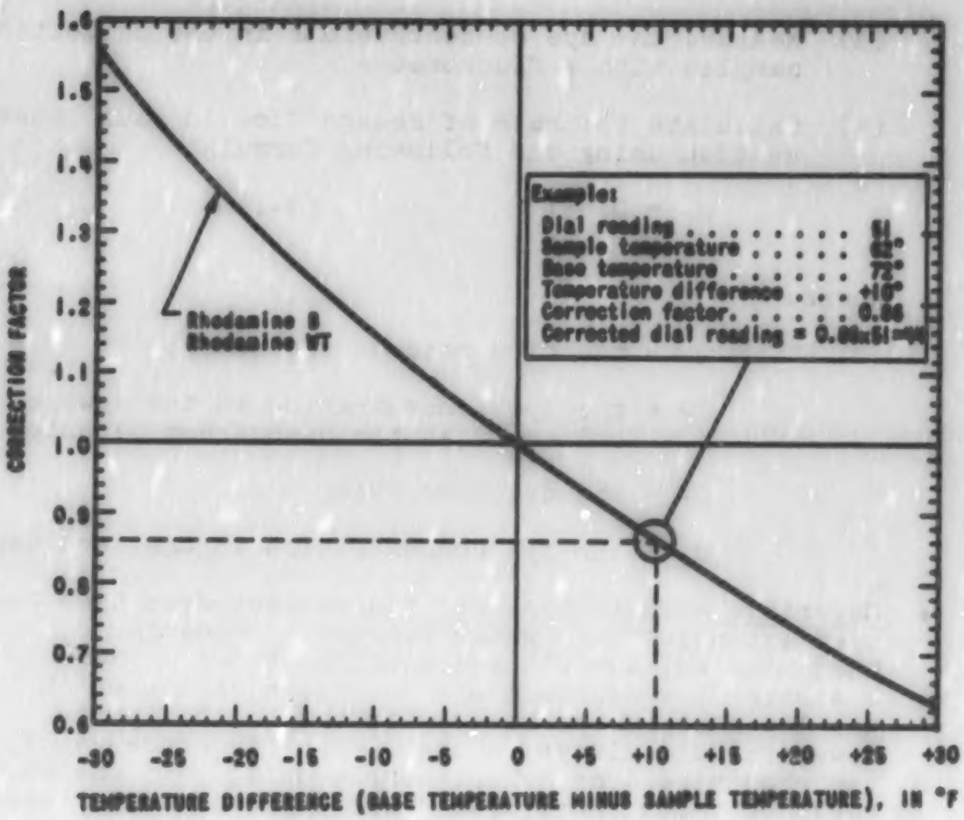

Figure 3-3. Temperature-correction curve for Rhodamine B and Rhodamine WT Dyes [2]

the dye at a constant rate to the manholes. Figures 3-4 and 3-5 show two solution feeders which can be assembled easily in the laboratory. In each of these feeders, the feeding rate can be changed by adjusting the head between the water surface in the tank and the opening of the inflow tube or orifice.

For collecting the samples at the downstream manholes, there is no need to enter the manhole. A container with a rope attached can be dropped down into the manhole to collect the sample. This would minimize the need for elaborate safety equipment. However, if the flows are small, it would still be more convenient to collect the samples by physically descending into the manholes. To minimize the loss of dye due to adsorption, the sample container should be made of high-quality glass, whenever possible. Plastic containers can also be used but ordinary soft-glass containers should be avoided. The samples should be allowed to stand to reach room temperature and to settle the suspended solids before being taken for measurement.

There are two fundamental types of fluorometers: (1) fluorescence spectrometers, or spectrofluorometers, and (2) filter fluorometers, or fluorimeters. The filter fluorometer is usually sufficient for an I/I study. Each fluorometer should be individually calibrated with standard dye solutions of known concentrations. A calibration curve should be obtained for each dye used. In the suitable concentration range, the calibration curve should show a linear relationship between the fluorometer readings and the dye concentrations. To avoid possible interferences by the solids or chemicals in the tap water, distilled water should be used to prepare the standard dye solutions.

The concentration, flow rate and quantity of the dye solution to be used should be determined before the flow measurement. To make such determinations, the total length of sewers to be studied and the approximate flow rate and flow velocity in the downstream sewer section should be estimated. The following example illustrates the calculation procedure:

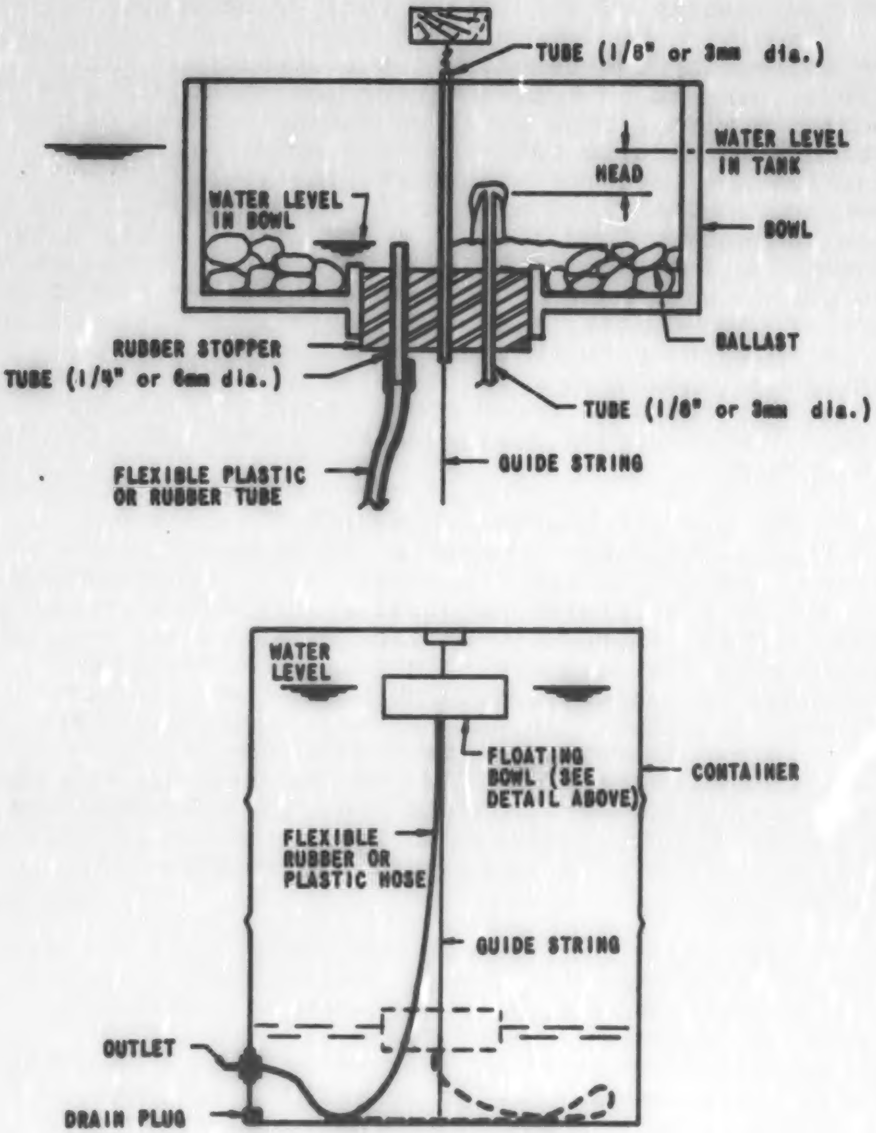
TUBE (1/8" or 3mm dia.)
WATER LEVEL IN TANK
HEAD
WATER LEVEL IN BOWL
BOWL
BALLAST
RUBBER STOPPER
TUBE (1/4" or 6mm dia.)
TUBE (1/8" or 3mm dia.)
FLEXIBLE PLASTIC OR RUBBER TUBE
GUIDE STRING
WATER LEVEL
FLOATING BOWL (SEE DETAIL ABOVE)
CONTAINER
FLEXIBLE RUBBER OR PLASTIC HOSE
GUIDE STRING
OUTLET
DRAIN PLUG

Figure 3-4. Floating Bowl Solution Feeder [3]

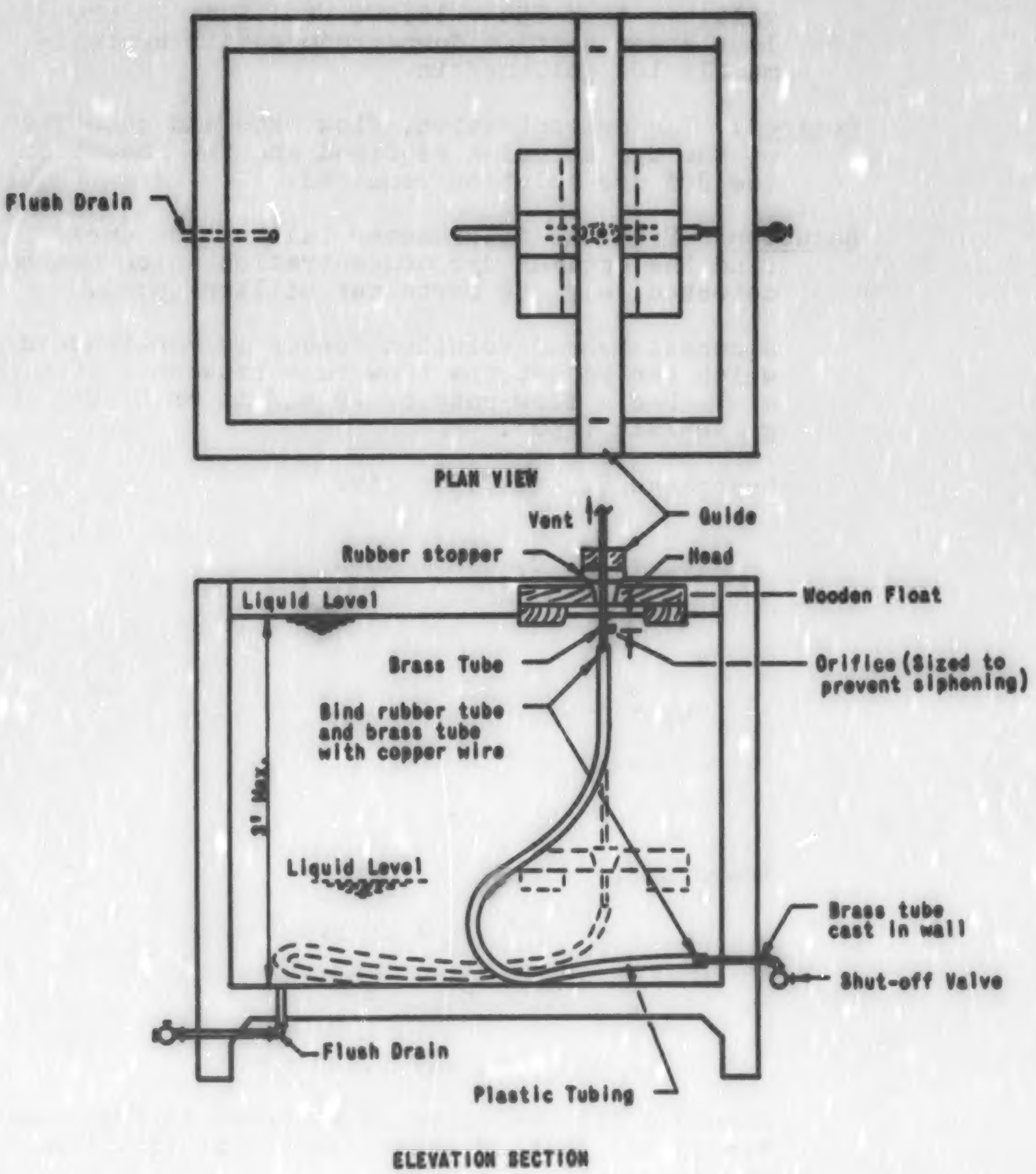
Flush Drain
PLAN VIEW
Vent
Guide
Rubber stopper
Head
Wooden Float
Liquid Level
Brass Tube
Orifice (Sized to prevent siphoning)
Bind rubber tube and brass tube with copper wire
3' Max.
Liquid Level
Brass tube cast in wall
Shut-off Valve
Flush Drain
Plastic Tubing
ELEVATION SECTION

Figure 3-5. Floating Platform Solution Feeder [4]

Example:

Given: Dye to be used - Rhodamine WT, 20% solution, specific gravity 1.19. Total length of sewer to be studied - 40 manholes at 250-foot intervals, or 40 x 250 = 10,000 ft. Flow in the last sewer section downstream equals approximately 100 gallons/min.

Desired: The concentration, flow rate and quantity of the dye solution required and the amount of the 20% dye solution required.

Solution: From the fluorometer calibration curve find the optimum dye concentration which can be detected, e.g. 50 parts per billion (ppb).

A constant-head solution feeder is constructed which can adjust the flow rate between 0-50 ml/min. Use a flow rate of 20 ml/min or 0.0053 gallon/min (gpm).

Rearrange Eq. (3-1) to give

$$C_1 = \frac{Q_f}{Q_1} C_f \qquad (3\text{-}2)$$

Where:

Q_f = 100 gpm;

C_f = 50 ppb;

Q_1 = 0.0053 gpm.

Therefore,

$$C_1 = \frac{100 \text{ gpm}}{0.0053 \text{ gpm}} \times 50 \text{ ppb}$$

$$= 9.4 \times 10^5 \text{ ppb}$$

$$= 940 \text{ ppm; say } 1{,}000 \text{ ppm}$$

Assume a flow velocity of 2 ft/sec in the sewer. For 10,000 feet of sewer, the total flow time would be:

$$\frac{10{,}000 \text{ ft}}{2 \text{ ft/sec}} = 5000 \text{ sec} = 83 \text{ min}$$

At a flow rate of 0.0053 gpm, the total dye solution required would be:

$$0.0053 \text{ gallon/min} \times 83 \text{ min} = 0.44 \text{ gallon}$$

Therefore, about 0.5 gallon of a 1000-ppm dye solution should be used for this part of the sewer system. The dye should be applied continuously at a constant rate of 20 ml/min until all the samples are collected from the downstream manholes. To insure that a sufficient quantity of dye solution is available, when feeding, approximately 1 gallon should be prepared.

To prepare 1.0 gallon of 1000-ppm dye solution from a 20% Rhodamine WT solution (Sp gr 1.19) the amount of the latter required can be calculated as follows:

20% solution = 2×10^5 ppm solution.
The amount of the 20% solution required to prepare 1.0 gallon of 1000-ppm solution

$$= \frac{1.0 \text{ gallon} \times 1000 \text{ ppm}}{2 \times 10^5 \text{ ppm} \times 1.19 \text{ (Sp gr)}}$$

$$= 4.2 \times 10^{-3} \text{ gallon}$$

The specific gravity of the solution should be taken into account because in the diluted dye solution the specific gravity is close to one, which is different from that of the concentrated solution.

For continuous flow monitoring, a fluorometer equipped with a flow-through door should be used. The samples are withdrawn from the sewer with a pump and fed to the fluorometer, where the dye concentrations are measured and recorded automatically on a strip-chart recorder. The pump is powered either by commercial-line power or by a gasoline driven generator. If the generator is used, a constant-voltage transformer is normally installed between the fluorometer and the generator supply to smooth out variations in generator output which might affect fluorometer readout. However, because of relatively high cost and possible interferences by the solids and the air bubbles in the samples, this technique is not normally recommended for continuous flow monitoring.

- **Advantages** -

  (1) Accurate
  (2) Saves time and provides flow data on many sewer sections

- **Disadvantages** -

  (1) Manpower involved
  (2) Maintenance cost
  (3) Expensive instrumentation cost

3.2.6.d Safety Measures

Entering manholes imposes a potential safety hazard which may be far more serious than many people think. The following facts should be realized:

(1) Poisonous and explosive gases, such as hydrogen sulfide, carbon dioxide, ammonia and methane, may accumulate in the manholes. Overexposure to these gases can kill a person. Flame or sparks can cause an explosion.

(2) The structure of a manhole may not be sound: the wall bricks may fall off; the steps may be corroded.

(3) Objects can fall through the manhole opening onto one's head; sharp objects such as broken glass, razor blades, etc., may cut one's hands and feet; a sudden increase in sewage flow in a large sewer may drown and sweep a person away; one can accidentally fall in a manhole due to various reasons.

(4) An open manhole without a guard and safety markers around it is dangerous to both the traffic above and the person working in the manhole.

To avoid any accident, proper safety precautions should always be observed when entering a manhole even for only a short period of time. Safety procedures should be developed in accordance with the Occupational Safety and Health Act (OSHA) and the Water Pollution Control Federation (WPCF) Manual of Practice No. 1. Before undertaking a manhole investigation project, the project engineer should review and summarize for his subordinates detailed information on safety procedures.

3.2.6.d (1) General Safety Precautions - The proper procedures and general safety precautions of entering a manhole for flow measurements or sewer inspection are summarized as follows:

(a) Always organize and plan the work before entering a manhole. Avoid prolonged stays in manholes.

(b) Prior to starting the work, all persons expecting to work in the manholes and the sewers should obtain typhoid and tetanus innoculations.

(c) Never enter a manhole without someone attending topside.

(d) Before opening a manhole, always place markers or traffic cones around it to caution the pedestrians and motorists. An open manhole should always be attended by a guard and have safety markers around it.

(e) Never smoke in or around a manhole.

(f) Use proper tools to open the manhole covers. Avoid hurting back, feet and fellow workers. The generally used tool is a manhole hook or crowbar.

(g) Before entering a manhole, determine if there are any explosive gases in it using an approved gas analyzer and, with the same analyzer, determine if there is sufficient oxygen in the manhole. Never assume that a manhole is safe because it was safe last time entered. Never assume that a manhole is safe because there is no smell of gas. If it is impossible to perform these tests or if the tests show that the explosive gas is present or the oxygen content is not sufficient, the manhole should be thoroughly purged with fresh air using an air blower and continuously ventilated using a 600 cubic feet per minute (cfm) air blower.

(h) Personal safety equipment (see Section 3.2.6.d(2)) should always be worn by the persons entering the manholes. Wear long trousers and heavy duty work shirts to avoid bruises and scrapes.

(i) Make sure that the manhole's brickwork is sound and that the steps can carry a person's weight. Watch out for slippery, broken, or loose steps, benches, etc.

(j) Never leave loose, small tools or other objects near an open manhole. To avoid being hit in the face or eyes by dropping objects, do not look up while in the manhole.

(k) Do not lift a person out of a manhole by his arm unless it is an emergency; this may cause a serious shoulder separation.

(l) Never tie a safety harness rope to a car or truck.

3.2.6.d (2) Personal Safety Equipment - The following is a list of the safety equipment that should be worn by all persons working in the sewer manholes at all times unless stated otherwise. All equipment should be OSHA approved.

(a) Hard Hats - Hard hats should be worn by all persons working in the manholes. On jobs where heavy machinery is involved, hard hats should also be worn while working outside of the manholes.

(b) Safety Harnesses and Rope - Safety harnesses should be worn by persons working in manholes. A safety rope is attached to the harness to allow the person on top of the manhole to quickly remove an injured or overcome person from a manhole and to prevent a person from being swept away by a high flow in a large manhole or sewer.

(c) Steel-Toed Work Shoes - These shoes are designed to protect the upper part of the foot from being hurt by falling objects and to protect the soles from being penetrated by sharp objects such as broken glass, razor blades, etc. These shoes are also designed for better foot support than ordinary shoes, being able to relieve some of the foot fatigue.

(d) Rubber Gloves - Rubber gloves should be worn by persons when hand contact with raw sewage or grouting chemicals is likely.

(e) Orange Safety Vests - These vests should be worn by persons working in or near any public road so they will be more visible to motorists.

(f) Goggles - Safety glasses or goggles should be worn by persons working in areas where chipped debris or chemicals may cause eye injury.

(g) Gas Ampoules - Gas ampoules are used to detect the presence of the following gases:

- Hydrogen Sulfide
- Methane
- Carbon dioxide

Gas ampoules should be put on before descending into a manhole and should be periodically checked to detect any overexposure.

3.2.6.d (3) Other Safety Equipment - Other equipment essential to the safety of the persons working in manholes and sewers is listed in Table 3-4.

3.2.7 Physical Condition of Sewer System

3.2.7.a General

If cost-effectiveness analysis (Section 3.4) is to be used to determine whether the infiltration/inflow in a sewer system is possibly excessive or nonexcessive, some field work may also have to be conducted to assess the general physical conditions of the sewer system.

Normally, due to time limitation, the physical condition of a sewer system cannot be thoroughly investigated in the infiltration/inflow analysis. Only the information essential for the cost-effectiveness analysis needs to be collected.

Some information about the physical condition of the sewer system may have been obtained from interviews and sewer maintenance records; however, additional information may have to be collected through other efforts, such as:

- Flow measurement in subsystems (Section 3.2.6),
- Physical inspection of key manholes and sewer lines (Section 4.2.4),
- Aboveground inspection (Section 4.2.2), and
- Smoke testing or rainfall simulation (Section 4.3).

For the convenience of cost-effectiveness analysis, it may be necessary to divide a sewer system into a number of subsystems (Section 3.2.6.b (3)) and consider each subsystem as an independent unit for the investigation.

Sufficient work should be performed to collect the information needed for formation of some sound bases for the estimation of:

- The work required to conduct a Sewer System Evaluation Survey (Chapter 4);

TABLE 3-4

SAFETY EQUIPMENT FOR MANHOLE AND SEWER INSPECTION [5]

First-aid kit

Self-contained breathing apparatus

Bump caps

MSA wristlets with 25 ft rope

Gas mask (H_2S)

Knee boots

Air blower, 3 HP, 1750 CFM

Air hose with air check

Aluminum ladder, 16 ft extension

Drop cord

Safety cones 28 in.

Isolation transformer (1.5 KVA, 50/60 HZ)

Beacon

Fire bottle (CO_2)

Fire extinguishers

Rain suits

- The portion of sewer lines requiring rehabilitation to remove the infiltration/inflow and the types of rehabilitation needed (Chapter 5); and

- The types and approximate number of inflow sources which may need correction (Chapter 5).

3.2.7.b Investigation Procedures

As a first step of investigation, flows in the key manholes of each subsystem should be measured so that the seriousness of infiltration/inflow problems in each subsystem can be evaluated. Infiltration and inflow are usually measured directly during the early morning hours (Section 3.2.6.b (2)). Subsystems with no apparent infiltration/inflow problems, as judged by the amounts of infiltration and inflow measured, can be eliminated from further investigation, and they should be excluded from the cost-effectiveness analysis.

One method which can be used to judge the seriousness of the infiltration problem is to compare the measured infiltration rates, in unit of gallons per day per inch diameter per mile with the installed infiltration specification allowance for the sewer lines under consideration. If the former is less than the latter, it can be concluded that there is no excessive infiltration in the sewer lines((Section 3.5).

If, after flow measurement, some subsystems are found to exhibit infiltration/inflow problems, the investigation can be continued by conducting a physical inspection of a few selected key manholes in each of these subsystems. The purpose of this inspection is to:

- Understand the general physical conditions of the manholes and sewers;

- Determine the types of infiltration/inflow sources and amount of flow from each source, if possible; and

- Determine the type and degree of deposits in the manholes and sewers.

To determine the types and general locations of the inflow sources in each subsystem, some aboveground inspection, smoke testing and/or rainfall simulation may also have to be performed.

(Detailed procedures for these investigations are given in Chapter 4).

3.3 DETERMINATION OF INFILTRATION/INFLOW

3.3.1 General Considerations

The determination of infiltration/inflow is one of the most important tasks in the Infiltration/Inflow Analysis. Without adequate flow information, it would be difficult to conduct either a cost-effectiveness analysis, or some other method of analysis to determine the existence or nonexistence of excessive infiltration/inflow in a sewer system; and, if the flow data are incorrect, false conclusions may result.

For the convenience of cost-effectiveness analysis and for establishing the design flow and criteria, the following flows are usually individually determined:

- Peak Infiltration
- Peak Inflow
- Peak Infiltration/Inflow
- Total Yearly Infiltration
- Total Yearly Inflow
- Total Yearly Infiltration/Inflow

The peak flow rates affect the sizing of the sewers and the pumping facilities. They also affect the sizing of the hydraulic treatment units, including clarifiers, chlorination units and plant pumping stations. In fact, even the biological treatment units can be affected by the sewage flow conditions. Sudden increases in sewage flow due to infiltration/inflow may wash out the active biomass from the aeration units and disturb the biological balance, resulting in reduced treatment efficiencies. Flow increase due to infiltration/inflow may also reduce the hydraulic detention time in the aeration units to a value insufficient for adequate biological reactions to take place. These situations may have to be remedied by either designing larger aeration units or adding a flow equalization basin, both of which increase the treatment costs.

The total annual quantities of infiltration and inflow should be determined for the estimation of the annual operation costs for the pumping and treatment facilities. Using the peak rates of infiltration and inflow for calculations will overestimate the operation costs.

The infiltration and the inflow should be individually estimated because the characteristics and sources of these two types of flows are quite different and their correction and treatment methods may also differ. By separate determinations, the significance of each type of flow can be individually recognized. And, in conducting the cost-effectiveness analysis, more realistic treatment alternatives can be formulated.

Often, however, it is not possible to precisely determine the infiltration and the inflow by their literal definitions. The infiltration determined from the dry weather high groundwater flow data may contain some amounts of inflow which are not related to rainfall. Similarly, the inflow determined from the wet weather flow data may also contain some amounts of infiltration which are induced by rainfall. Without in-depth field investigations, it is almost impossible to separate the two flows in either of these two cases. The flows determined in the former case may be more aptly termed the "dry weather infiltration/inflow"; and the latter, the "wet weather infiltration/inflow" or the "rainfall associated infiltration/inflow". For the purpose of determining whether there is possibly excessive infiltration/inflow, normally these flows can readily be used for conducting the cost-effectiveness analysis; in either case, it is not necessary to accurately determine the individual flows.

When sewage flow data and other pertinent information are available, normally the infiltration and inflow can be readily determined without additional flow measurements. Conversely, if there are no sewage flow data and other pertinent information or if the data and information are insufficient or inaccurate, a flow measurement program should be initiated to gather sufficient information for infiltration/inflow determination (Section 3.2).

The information which is normally needed for infiltration and inflow determinations includes:

- Sewage flow data,
- Water consumption records,
- Rainfall data, and
- Groundwater records.

Under appropriate conditions, infiltration/inflow in a sewer system may also be directly measured.

3.3.2 Determination of Infiltration/Inflow Using Wastewater Flow Data

3.3.2.a Introduction

The wastewater flow data to be used for infiltration/inflow determination may come from either existing flow records or records of flow measurements conducted during the study period. The records may be either long term (i.e., one year or more), or short term. They may be collected from either one terminal flow measurement station, such as a sewage treatment plant, or several stations in the sewer system. The basic procedures of determining infiltration/inflow using all such flow data are similar.

3.3.2.b Determination of Infiltration/Inflow Using Long-Term Flow Data From One Measurement Station

Basically, the procedure includes the following steps:

(1) Determination of theoretical wastewater production rate,

(2) Determination of total yearly infiltration/inflow,

(3) Determination of total yearly infiltration,

(4) Determination of total yearly inflow,

(5) Determination of peak infiltration,

(6) Determination of peak inflow, and

(7) Determination of peak infiltration/inflow.

3.3.2.b (1) Determination of Theoretical (or Base) Wastewater Production Rate - The theoretical wastewater production rate is the rate of wastewater flow which should be expected in a sewer system if there is no infiltration/inflow. This rate is usually determined from water consumption data. The frequently used design average wastewater flow of 100 gallons per capita per day should not be used for such purpose because the actual per capita wastewater production rate in an area may be different from this arbitrarily chosen figure.

For infiltration/inflow determinations, generally, it is only necessary to derive an annual average theoretical wastewater production rate. However, in locations where large fluctuations of water consumption and wastewater flow rates occur due to seasonal change in population or other reasons, seasonal or monthly wastewater production rates may have to be determined.

The water consumption data used for this determination should be of the same year, or immediate previous year, as the wastewater flow data to be used for the determination of infiltration/inflow. Data from a different year can also be used if it can be substantiated that there has been no significant change in water consumption in the two years. This precaution is necessary for the derivation of reasonable infiltration/inflow rates.

If metered water use data are available, the theoretical wastewater production can be determined by estimating the percentage of the water which would reach the sewer system. In general, 80 to 90% of the residential water use would reach the sewers. Industrial plants may or may not treat and discharge their wastewaters separately; the amounts of wastewater discharged to the sewer system under study should be individually determined.

If no metered water use data are available, the total water consumption (or, water production) data can be used. To determine the theoretical wastewater production from the water consumption data, one should realize that not all the water consumed reaches the sewer system. Portions of the consumed water may be lost through a number of routes, such as:

- Lawn watering,
- Irrigation,
- Car washing,
- Fire fighting, hydrant testing,
- Separate treatment and disposal of wastewater by industries,
- Subsurface disposal by septic tank users, and
- Leakage from water mains, and service pipes.

These losses should be properly estimated and deducted from the total water consumption rate to derive the theoretical wastewater production rate. In general, 60 to 80% of the water consumption will become sewage.

The wastewater separately treated and disposed of by industries and the water lost to fire fighting and septic tank subsurface disposal areas can normally be estimated rather accurately by reviewing related records. The water loss from pipe leakage may be estimated by comparing pumping and water meter records.

The water losses to lawn watering, irrigation, car washing, etc. are usually not easy to determine. However, for most northern states, the water losses in this category are usually small during the winter months. Therefore, the annual average theoretical wastewater production rate may be assumed to be approximately equal to the average water consumption rate for the winter months minus the water losses due to private and industrial wastewater disposals, fire fighting, pipe leakage, etc., if these losses are found to be significant. In southern states, the water losses to lawn watering, irrigation, car washing, etc., may still be significant even in winter and they still have to be properly estimated and deducted from the total water consumption rate to derive the theoretical water production rate.

3.3.2.b (2) Determination of Total Yearly Infiltration/Inflow - To determine the total yearly infiltration/inflow and the general nature of the infiltration/inflow problem in a sewer system, the following procedure is recommended:

(a) Calculate the average monthly, average weekly, or daily wastewater flows for the year(s) for which records have been obtained.

(b) Plot these average flows against time (see Figure 3-6).

(c) Plot the theoretical wastewater production rate, rainfall and groundwater levels on the same plot.

(d) On this plot, measure the total area above the theoretical wastewater production curve and below the wastewater flow curve for each one-year period. This area would represent the total yearly infiltration/inflow. If more than one year's total infiltration/inflow can be determined, the highest figure should be used.

(e) On the same plot, measure the total area, if any, below the theoretical wastewater production curve and above the wastewater flow curve for each one year period. This area could represent the total yearly exfiltration in the sewer system. (This situation is not demonstrated in Figure 3-6).

(f) Compare the curves for wastewater flow, rainfall and groundwater to reveal their inter-relationships.

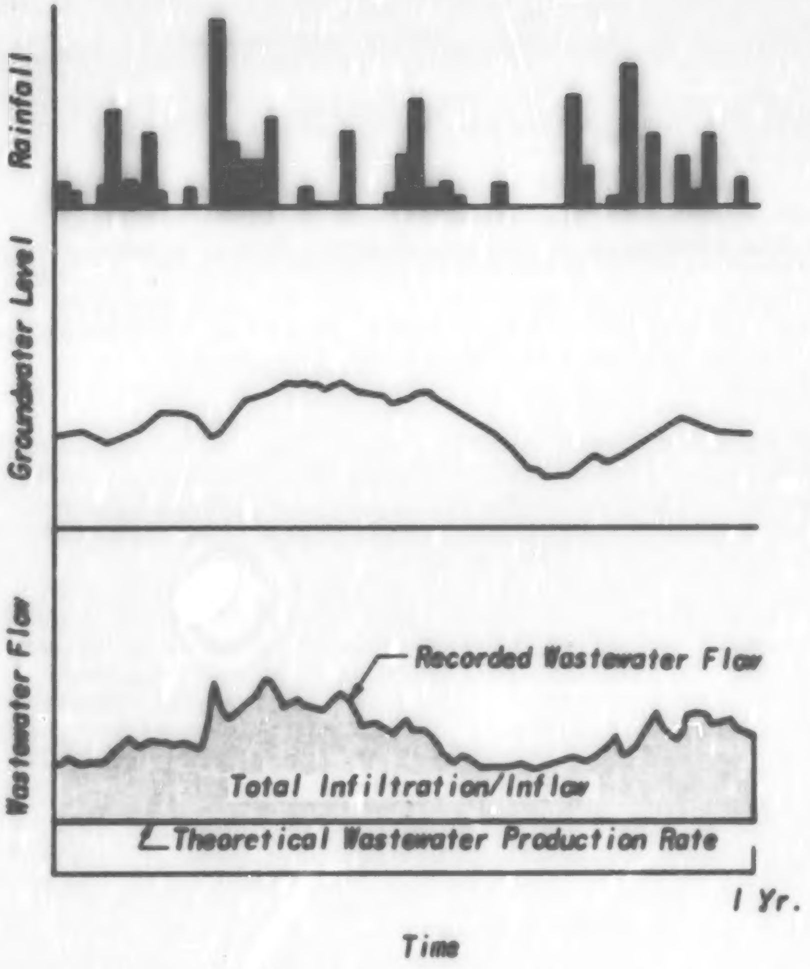

Figure 3-6. Determination of Total Yearly Infiltration/Inflow

If the plot indicates no exfiltration in the sewer system, the total yearly infiltration/inflow may also be directly calculated by subtracting the total yearly theoretical wastewater production from the total yearly wastewater flow.

3.3.2.b (3) Determination of Total Yearly Infiltration - The total yearly infiltration can be determined by the following procedure:

(a) From the plot generated by the procedure outlined in the previous section (Figure 3-6), select several months with typical wastewater flow conditions, including highest, lowest and average flow conditions. The months in which exfiltration is suspected to have occurred should also be included.

(b) For each of these months, plot the daily wastewater flow, the theoretical wastewater production rate and the rainfall data against the time (Figure 3-7). If groundwater data are available, they can also be shown in the same plot.

(c) For each month, estimate the lower limit of the wastewater flow curve corresponding to the flows for nonrainfall days. Measure the area between this limit and the theoretical wastewater production rate. This area would represent the base infiltration, or exfiltration, for the month (Figure 3-7).

(d) Calculate the average of the base infiltration for all typical flow months, adjust it with estimated exfiltration rates, if any, and project it to a yearly total. The latter would represent the total yearly infiltration.

The total yearly infiltration determined in the above manner may also include some amounts of sustained inflow which enter the sewers during nonrainfall days, such as cooling water discharges, drains from springs and swampy areas, foundation drains, etc. Therefore, the determined flow could be more properly termed "the total yearly dry weather infiltration/inflow."

If the sustained inflow can be determined during the study period, it should be subtracted from the flow derived through the above procedure to determine the "true" total yearly infiltration. However, for the cost-effectiveness portion of the Infiltration/Inflow Analysis, it is generally not necessary to make this correction.

3.3.2.b (4) Determination of Total Yearly Inflow - After the total yearly infiltration/inflow and total yearly infiltration have been determined, the total yearly inflow may be calculated by subtracting the latter from the former.

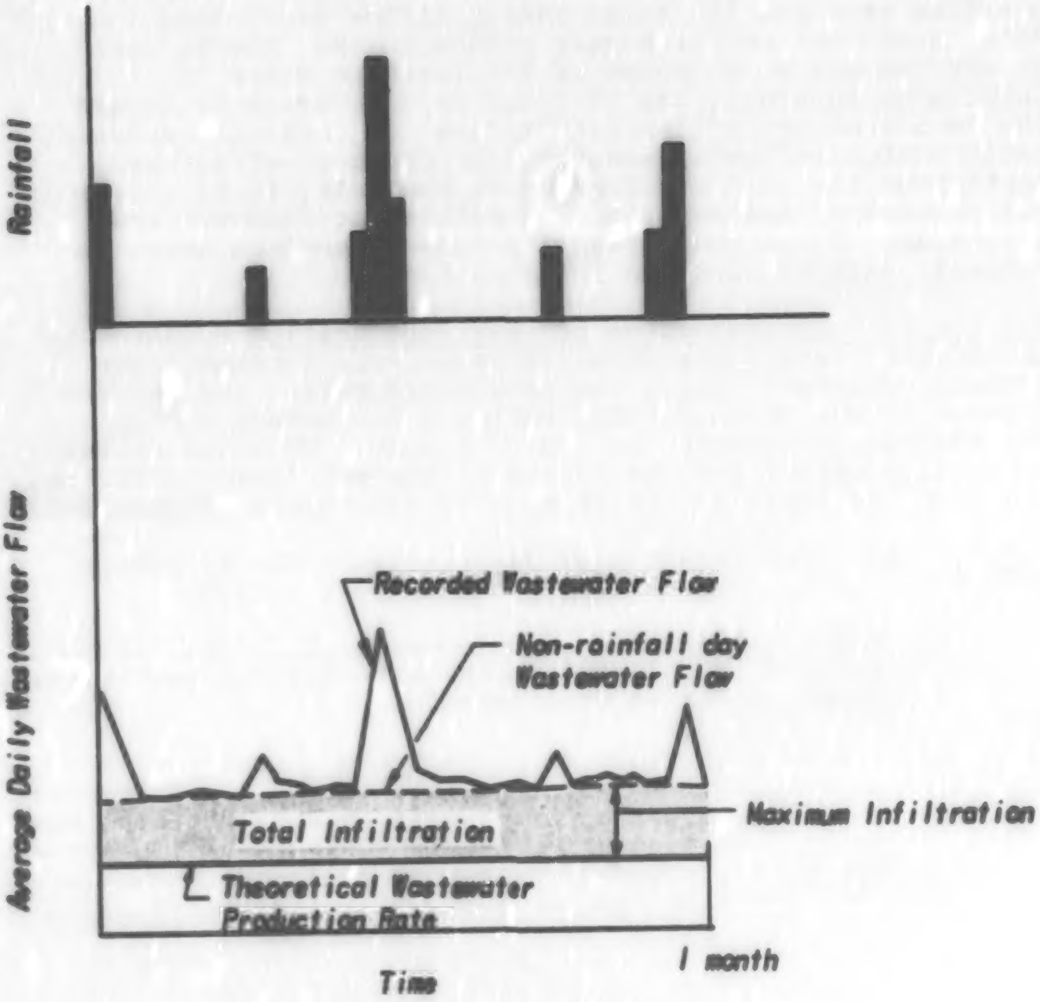

Figure 3-7. Determination of Total Yearly Infiltration

Just as the total yearly infiltration determined in the previous section, the total yearly inflow determined in this manner may not be purely inflow in the literal sense. It may contain some amount of infiltration which is induced by rainfall, and it could be more properly termed the "wet weather infiltration/inflow" or "rainfall associated infiltration/inflow". However, for the cost-effectiveness portion of the Infiltration/Inflow Analysis, it is generally not necessary, and may not be possible, to find out what percentage of the total yearly inflow determined above is actually rainfall-induced infiltration.

3.3.2.b (5) Determination of Peak Infiltration - Since the groundwater levels are normally relatively constant over periods of several days, the peak infiltration can be considered as the maximum infiltration which occurs during the maximum groundwater period of a year. From the wastewater flow curves for the months of highest flow conditions, the peak infiltration can be readily determined (Figure 3-7).

3.3.2.b (6) Determination of Peak Inflow - The following procedure may be used to determine the peak inflow:

(a) Carefully examine the wastewater flow and rainfall records to select the days with highest wastewater flows and heaviest rainfalls.

(b) For each of these days, plot the actual hourly wastewater flow rates against time. All emergency pumpings, bypasses and overflows should be included in each corresponding hourly wastewater flow curve. The hourly rainfall data should also be shown in the same plot (Figure 3-8).

(c) Superimpose on each of the above flow curves a typical hourly wastewater flow curve for one of the nearest nonrainfall days (Figure 3-8).

(d) Measure the difference in flow for each hour between each set of two flow curves described in Steps b and c and record the maximum difference for each day.

(e) Compare the maximum flow differences for all the days considered and select the peak value. This peak value would represent the peak inflow in the sewer system.

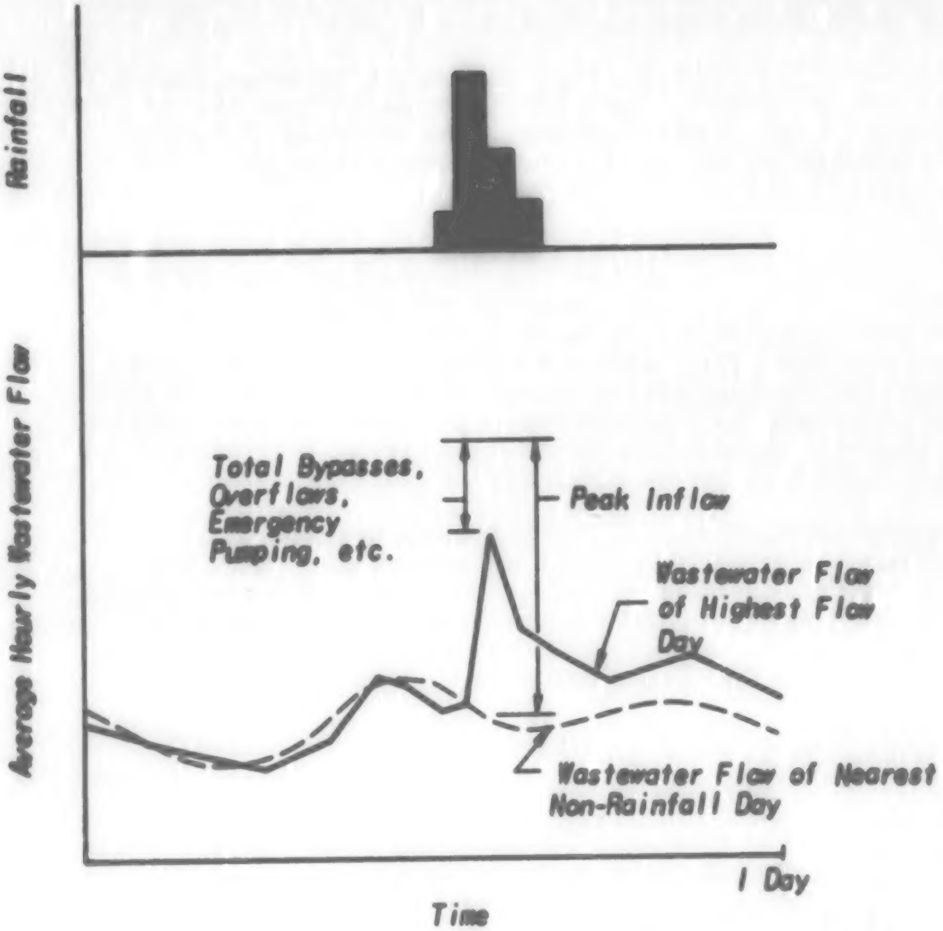

Figure 3-8. Determination of Peak Inflow

3.3.2.b (7) Determination of Peak Infiltration/Inflow -

The peak infiltration/inflow can usually be approximated as the sum of peak infiltration and peak inflow separately determined above.

3.3.2.c Determination of Infiltration/Inflow Using Long-Term Flow Data From Several Flow Measurement Stations

If the wastewater flow data is from several flow measurement stations in a sewer system, the infiltration/inflow can be determined separately in each subarea contributing flows to the flow measurement station, following the procedure described in Section 3.3.2.b.

In order to do so, the water consumption data for each subarea should be obtained to derive the theoretical wastewater production rate. If it is not possible to obtain such data, then the sewered population in each subarea should be determined. From the total water consumption and the total sewered population in the entire sewer system, the per capita water consumption rate can be determined. Multiplying this rate by the sewered population in each subarea, the water consumption in each can be determined.

If the sewer system handles industrial wastewaters, the industrial water consumption should be subtracted from the total water consumption before the aforementioned calculations. The industrial wastewaters in each subarea should be individually determined and added to the theoretical wastewater production rate derived by using the adjusted water consumption value.

3.3.2.d Determination of Infiltration/Inflow Using Short Term Flow Data

For the purpose of this discussion, the short term is defined as a period (or periods) of less than one year. Wastewater flow data covering a period (or periods) of shorter than one year may also be used to determine the infiltration/inflow if the period (or periods) covers all representative groundwater and rainfall conditions, including high, low and average conditions, in the study area. The following are the recommended procedures:

(1) Determine the total infiltration/inflow, total infiltration and total inflow in each period for which wastewater flow data has been obtained, following procedures similar to those outlined in Section 3.3.2.b (1) through 3.3.2.b (4).

(2) Calculate the sum of all total infiltration determined in Step 1 and the sum of total days in the period or periods. Determine the average daily infiltration by dividing the total infiltration by the total sum of days. Determine the total yearly infiltration by multiplying this final average daily infiltration by the total number of days in a year.

(3) Calculate the sum of all total inflow determined in Step 1 and the sum of all rainfalls which occurred in the flow measurement periods. Determine the total yearly inflow by dividing the sum of total inflows by the sum of all rainfalls which occurred in the flow measurement periods and multiplying the result by the average yearly rainfall.

(4) Calculate the total yearly infiltration/inflow by adding the total yearly infiltration and total yearly inflow.

(5) Determine the peak infiltration, peak inflow and peak infiltration/inflow following the same procedures outlined in Sections 3.3.2.b (5) through 3.3.2.b (7).

3.3.3 Determination of Infiltration/Inflow by Direct Flow Measurement

3.3.3.a Introduction

The infiltration/inflow in a sewer system can also be determined by measuring the infiltration and the inflow directly. Flow measurement requirements and general procedures have been presented previously (Section 3.2.6). The procedures for the calculation of yearly total and peak flows are discussed in the following subsections.

3.3.3.b Determination of Total Yearly Infiltration

(1) List all measured infiltration. (The measurements should have covered all typical groundwater conditions of a year.) Adjust the flow values by subtracting from them all wastewater flows which might have entered the sewers during flow measurement periods, including domestic, commercial and industrial flows, and adding to them all flows which might have left the sewer system in the same periods, such as overflows, bypasses, etc.

(2) Calculate the total infiltration in each typical groundwater period, assuming that the infiltration is constant throughout the entire period and equal to the infiltration rate measured during the period.

(3) Calculate the sum of all total infiltration derived. This sum would be the total yearly infiltration.

(4) If flow measurements were conducted in more than one station, the total yearly infiltration in each subsystem should be determined and added together to obtain the total yearly infiltration for the entire system.

3.3.3.c Determination of Total Yearly Inflow

(1) Determine the total inflow during each rainfall period using the hydrograph on the flow recording chart. Adjust the flow values by subtracting from them all wastewater flows which might have entered the sewers during flow measurement periods, including domestic, commercial and industrial flows, and adding to them all flows which might have left the sewer system in the same periods, such as overflows, bypasses, emergency pumpings, etc.

(2) Calculate the sum of all total inflows and the sum of rainfalls which occurred during all inflow measurement periods.

(3) Calculate the total yearly inflow by multiplying the sum of all total inflows derived above by the average yearly rainfall in the study area and then dividing it by the sum of rainfalls which occurred during all inflow measurement periods.

(4) If flow measurements were conducted in more than one station, the total yearly inflow in each subsystem should be determined and added together to obtain the total yearly infiltration for the entire system.

3.3.3.d Determination of Total Yearly Infiltration/Inflow

The total yearly infiltration/inflow is the sum of the total yearly infiltration and total yearly inflow determined in the previous two subsections.

3.3.3.e Determination of Peak Infiltration

The peak infiltration can be approximated as the infiltration measured during the highest groundwater period of a year, with proper adjustments for wastewater flows entering the sewer system and overflows, bypasses, etc. leaving the system during the flow measurement period.

3.3.3.f Determination of Peak Inflow

The peak inflow can be assumed to be the maximum instantaneous inflow recorded during flow measurement periods. Adjustments should also be made for all wastewater flows entering the sewer system and overflows, bypasses, emergency pumpings, etc., leaving the system during the flow measurement period.

3.3.3.g Determination of Peak Infiltration/Inflow

The peak infiltration/inflow can be approximated as the sum of peak infiltration and peak inflow determined in the previous two subsections.

3.3.4 Adjustment for Peak Inflow

The peak inflow determined by the above procedures should be adjusted for the desired design period or design condition. The design rainfall frequency normally used for designing storm sewers in the area under study should be used for such adjustment. The ratio of the design and observed rainfall intensities is used to adjust the peak inflow.

3.4 COST-EFFECTIVENESS ANALYSIS

3.4.1 Introduction

For the purpose of determining whether the infiltration/inflow in a sewer system is possibly excessive or nonexcessive, a cost-effectiveness analysis may be conducted. Infiltration/inflow is defined as being possibly excessive if the total costs for the correction of infiltration/inflow conditions are less than the total costs for transportation and treatment of these flows. The cost-effectiveness analysis, however, is not the only method which may be used; other methods may also serve the same purpose (Section 3.5).

The basic information which is needed for the cost-effectiveness analysis includes:

- Average and peak wastewater flows (including domestic, commercial and industrial flows) for the design year of treatment facilities;

- Peak and total yearly infiltration and inflow in the entire sewer system and/or in the subsystems;
- General physical conditions of sewer system; and
- Capacities of existing sewers, pumping stations and treatment facilities.

The design wastewater flows should be developed on the basis of population and water consumption projections as well as infiltration allowances for new sewers, as ordinarily practiced in the planning of treatment facilities. In addition, the bypasses and overflows in the sewer system should also be quantitatively determined.

The peak and total yearly infiltration and inflow may be determined by one of the methods presented in Section 3.3.

The physical conditions of the sewer system can be investigated following the procedures discussed in Section 3.2.7.

Information about the capacities of the existing sewers, pumping stations and treatment facilities is normally available from other phases of study in facilities planning.

Once the above information has been gathered, the costs for transportation and treatment of wastewater (including infiltration/inflow) and for correcting the infiltration/inflow conditions can be estimated. This is followed by an analysis of the cost data to determine the existence or nonexistence of excessive infiltration/inflow. Detailed procedures for cost estimations and analysis are presented in the following subsections.

The cost-effectiveness analysis should be conducted in accordance with the "Cost-Effectiveness Analysis Guidelines" published in the Federal Register 40 CFR 35. [6]

In the following discussions, the infiltration and inflow are considered together for cost-effectiveness analysis; but, in some cases, engineers may find it more convenient to conduct separate analyses for infiltration and inflow, following the same procedures.

3.4.2 Cost Estimation

3.4.2.a Introduction

For cost-effectiveness analysis, two types of costs are developed:

- Costs for correction of infiltration/inflow conditions; and

- Costs for transportation and treatment of wastewater (including infiltration/inflow).

For the convenience of cost comparison, all costs should be converted to their present worth or average annual equivalent values. The facility planning period and the most current interest rate (currently 6 1/8%) should be used for the conversion. (The interest rate is published in the Federal Register annually by the Water Resources Council).

3.4.2.b Sources of Cost Information

Cost information for the correction of infiltration/inflow conditions usually can be obtained from sewer inspection and rehabilitation companies. (Some cost data are presented in Chapter 6.)

Cost information for the construction of sewers and sewage treatment facilities can be obtained from contractors, equipment manufacturers, as-bid construction estimates and various cost estimation publications.

Operation and maintenance costs can be determined by estimating the operation and maintenance needs in each type and size of treatment facility or sewer system and their associated costs.

3.4.2.c Cost Estimation for Correction of Infiltration/Inflow Conditions

3.4.2.c (1) Introduction - For the correction of infiltration/inflow conditions, two major tasks have to be conducted:

- Sewer System Evaluation Survey

- Sewer System Rehabilitation

The costs required for conducting both tasks should be estimated.

3.4.2.c (2) Costs for Sewer System Evaluation Survey - The Sewer System Evaluation Survey is needed to locate sources of infiltration/inflow, quantify the flows from each source and determine the most cost-effective way of correcting the infiltration/inflow conditions. The Evaluation Survey can be accomplished through the following functions:

- Physical survey,

- Rainfall simulation,

- Preparatory cleaning,
- Internal inspection, and
- Preparation of report.

(Details of these functions are discussed in Chapter 4.)

Not all of these functions, nor all of the tasks within each function, need to be included in each Evaluation Survey. Only those functions judged to be necessary should be included in the cost estimates.

Before the costs can be derived, the scope of work must be first estimated. Data collected during the study can be used to estimate the amount of work needed. The following are the suggested procedures:

(a) Determine the number of subsystems to be included.

If the cost-effectiveness analysis is to be conducted using Methods 1 and 2 in Section 3.4.3, the entire sewer system is considered as a single study unit.

If the analysis is to be conducted using Method 3, the system should be divided into several subsystems and the infiltration/inflow condition in each subsystem studied individually.

The subsystems to be included in the cost-effectiveness analysis are those which are suspected of having serious infiltration/inflow problems. One of the methods which can be used to single out these areas is to determine the infiltration and inflow (through either direct flow measurements or analysis of wastewater flow data; see Section 3.3) in each designated subsystem, and compare the flow rates with some reasonable criteria.

- To determine whether there is an infiltration problem in a subsystem, the infiltration rate, in gallons per day per inch diameter per mile pipe, can be compared with the infiltration specification allowance for the pipe when installed. If the former is greater than the latter, it can be concluded that there is a possible infiltration problem in the subsystem and the subsystem may be included in the cost-effectiveness analysis insofar as infiltration is concerned. Some Regulatory Agencies utilize a rule of thumb indicating infiltration rates of 1,000 gallons per day per inch diameter per mile of pipe or less as nonexcessive.

- To determine whether there is an inflow problem in a subsystem, while there is no criterion as in the infiltration case, the flow rates can still be used to formulate a judgment. Thus, for example, if the quantity of inflow is very small, say a few thousand gallons per day, there is probably no inflow problem in the subsystem at all. The apparent value of inflow may be caused by the rainwater entering the sewers through infiltration sources, such as pipe cracks, etc., due to the increase in groundwater level during the rain period, or it may be simply caused by the flow measurement instrument limitations or calculation omissions/or assumptions.

  If, after a careful analysis, one is confident that there is no inflow problem in a subsystem, the subsystem should be excluded from the cost-effectiveness analysis as far as inflow is concerned.

All subsystems found to have either infiltration or inflow problems, or both, should be included in the analysis. For subsystems with only infiltration problems, only the costs for correcting infiltration conditions should be included in the cost-effectiveness analysis. Similarly, for subsystems with only inflow problems, only the costs for correcting inflow conditions should be included. When both infiltration and inflow are problems, the costs for correcting both conditions should be included.

In the subsequent estimation procedures, each subsystem selected for analysis should be considered as a separate study unit.

(b) Estimate the amount of work required for Physical Survey.

The following tasks may have to be conducted in Physical Survey:

- Aboveground inspection,
- Flow monitoring, and
- Manhole and sewer inspection.

A plan of action for performing these tasks should be first prepared. The manpower and equipment requirements can then be estimated.

All manholes in a system or subsystem may not need to be entered, as the flow monitoring program may eliminate some subareas from further investigation. The total number of manholes that need to be inspected should be properly estimated. Results from the study of the physical condition of the sewer system (Section 3.2.7) can be especially helpful for such estimation. After a number of randomly selected manholes and sewer lines have been inspected, the general condition of the sewer system could be estimated by proportional projection.

(c) Estimate the amount of work required for rainfall simulation.

Both infiltration and inflow sources can be located by rainfall simulation. The simulation can be accomplished by one or a combination of the following techniques:

- Smoke testing,
- Dyed water testing, and
- Water flooding test.

The lengths of pipes and trenches, total number of houses and other possible inflow sources in a system or subsystem which need to be investigated by each rainfall simulation technique should be estimated.

Results from interviews (Section 3.2.1), map study (Section 3.2.2.b), study of physical condition and other information obtained during the study can all be utilized to make the estimate.

(d) Estimate the length of sewer pipes which need to be cleaned and internally inspected.

Results from the study of the physical condition of the sewer system (Section 3.2.7) and the existing sewer system maintenance records should have provided some information for such estimation.

Not all the sewers in a system or subsystem may need to be cleaned or inspected, or both.

(e) Estimate the manhours required for the preparation of an Evaluation Survey Report.

This can be done based on experience obtained from previous jobs of a similar nature. The manhour requirement would depend on the size of the system and the magnitude of the infiltration/inflow problem.

After the scope of work has been established, the unit cost for conducting each task can be obtained from proper sources (Section 3.4.2.b), and the total costs can be derived. (See Table 3-5.)

3.4.2.c (3) Costs for Sewer System Rehabilitation - The sewer system rehabilitation is needed to remove the infiltration/inflow sources from the sewer system. The work involves the repair and/or replacement of sewers and manholes and the disconnection or plugging of inflow sources. (Details of the rehabilitation techniques are presented in Chapter 5.)

Again, for cost estimation, the required rehabilitation work should be first estimated. All data obtained during the study should be synthesized and analyzed to provide a basis for such estimation. (See Table 3-6.)

3.4.2.d Cost Estimation for Transportation and Treatment of Wastewater

3.4.2.d (1) General Considerations - Cost estimates for transportation and treatment should be based on some preliminary designs. For all designs, only the most cost-effective and technically and environmentally feasible alternatives should be used. In addition, the following items should be considered:

(a) Bypasses and overflows: In separated sanitary sewer systems, bypass and overflow may or may not be allowed depending on the Reliability Class of the facility and the conditions stated in the NPDES permit. All such flows in the sewer system should be considered and included in the derivation of the total design flows.

In combined sewer systems, the requirements for the control or treatment of bypass or overflow are stated in the NPDES permit. If the permit does not require control or treatment of bypasses or overflows, the bypasses or overflows attributable to the combined sewer inflow should not be included in the total design flows. On the other hand, if the permit requires control or treatment of combined sewer bypasses or overflows, these flows should be included in the total design flows.

TABLE 3-5

WORK SHEET FOR QUANTITY TAKE-OFF AND COST ESTIMATION - SEWER SYSTEM EVALUATION SURVEY

Subsystem No.________ Page________

Function	Estimated Quantity		Estimated Cost	
	Quantity	Unit	Unit Cost, $/Unit	Total Costs, $
1. PHYSICAL SURVEY				
Above Ground Inspection		Manhour		
Flow Monitoring		Manhour		
Manhole & Sewer Inspection		ft (m)		
Subtotal				________
2. RAINFALL SIMULATION				
Smoke Testing		ft (m)		
Dyed Water Testing		ft (m)		
Water Flooding Test		ft (m)		
Subtotal				________
3. PHYSICAL SURVEY REPORT		Manhour		
4. PREPARATORY CLEANING				
6-inch pipe		ft (m)		
8-inch pipe		ft (m)		
10-inch pipe		ft (m)		
12-inch pipe		ft (m)		
15-inch pipe		ft (m)		
18-inch pipe		ft (m)		
21-inch pipe		ft (m)		
24-inch pipe		ft (m)		
27-inch pipe		ft (m)		
30-inch pipe		ft (m)		
36-inch pipe & up		ft (m)		
Subtotal				________
5. INTERNAL INSPECTION				
6-inch pipe		ft (m)		
8-inch pipe		ft (m)		
10-inch pipe		ft (m)		
12-inch pipe		ft (m)		
15-inch pipe		ft (m)		
18-inch pipe		ft (m)		
21-inch pipe		ft (m)		
24-inch pipe		ft (m)		
27-inch pipe		ft (m)		
30-inch pipe		ft (m)		
36-inch pipe & up		ft (m)		
Subtotal				________
6. ENGINEERING SERVICE & REPORT		Manhour		
TOTAL EVALUATION SURVEY COST				________

TABLE 3-6

WORK SHEET FOR QUANTITY TAKE-OFF AND COST ESTIMATION - SEWER SYSTEM REHABILITATION

Subsystem No.________

Page________

Function	Estimated Quantity		Estimated Cost	
	Quantity	Unit	Unit Cost, $/Unit	Total Cost $
I. CORRECTION OF INFILTRATION CONDITIONS				
Sewer Replacement				
6-inch pipe		ft (m)		
8-inch pipe		ft (m)		
10-inch pipe		ft (m)		
12-inch pipe		ft (m)		
15-inch pipe		ft (m)		
18-inch pipe		ft (m)		
21-inch pipe		ft (m)		
24-inch pipe		ft (m)		
27-inch pipe		ft (m)		
30-inch pipe		ft (m)		
36-inch pipe		ft (m)		
48-inch pipe & up		ft (m)		
Subtotal				________
Pipe Lining				
6-inch pipe		ft (m)		
8-inch pipe		ft (m)		
10-inch pipe		ft (m)		
12-inch pipe		ft (m)		
15-inch pipe		ft (m)		
18-inch pipe		ft (m)		
21-inch pipe		ft (m)		
24-inch pipe		ft (m)		
27-inch pipe		ft (m)		
30-inch pipe		ft (m)		
36-inch pipe		ft (m)		
48-inch pipe & up		ft (m)		
Subtotal				________
Chemical Grouting				
6-inch pipe				
8-inch pipe				
10-inch pipe				
12-inch pipe				
15-inch pipe				
18-inch pipe				
21-inch pipe				
24-inch pipe				
27-inch pipe				
30-inch pipe				
36-inch pipe				
48-inch pipe & up				
Subtotal				________

TABLE 3-6 (Continued)

WORK SHEET FOR QUANTITY TAKE-OFF AND COST ESTIMATION - SEWER SYSTEM REHABILITATION

Subsystem No.________ Page__________

Function	Estimated Quantity		Estimated Cost	
	Quantity	Unit	Unit Cost, $/Unit	Total Cost $
Manhole Wet Well Replacement		each		
Manhole Wet Well Repair		each		
Faculty Taps Repair		each		
House Service Pipe Replacement		each		
House Service Pipe Repair		each		
Total Cost for Infiltration Correction				______
II. CORRECTION OF INFLOW CONDITIONS				
Low-lying Manhole Raising		each		
Manhole Cover Replacement		each		
Cross Connection Plugging		each		
Roof Leader Drain Disconnection		each		
Foundation Drain Disconnection		each		
Cellar Drain Disconnection		each		
Yard Drain Disconnection		each		
Area Drain Disconnection		each		
Cooling Water Discharge Disconnection		each		
Drains from Springs and/or Swampy Areas Plugging		each		
Total Cost for Inflow Corrections				______
III. ENGINEERING SERVICES		Lump Sum		
IV. LEGAL FISCAL AND ADMINISTRATIVE SERVICES		Lump Sum		
V. CONTINGENCY		Lump Sum		
VI. INTEREST DURING CONSTRUCTION		Lump Sum		
VII. SALVAGE VALUE		Lump Sum		______
TOTAL REHABILITATION COST				______

(b) Capacities of existing facilities: The capacities of the existing sewers, pumping units and treatment facilities should be evaluated to determine whether additional construction of these facilities will be needed in the design year to handle the anticipated wastewater flows and the infiltration/inflow remaining in the system.

Special attention should be directed to the areas where there are known problems such as manhole overflow, pipe surcharge, basement sewage backup, etc. Relief sewers, pipe realignment, holding ponds, etc., may be considered among other transportation and treatment alternatives to alleviate these problems.

(c) Design Flows: The flows which are needed for the design of transportation and treatment facilities are:

- Average and peak normal wastewater flows in the design year,
- Peak infiltration,
- Peak inflow, and
- Peak infiltration/inflow.

The sum of the peak infiltration, which normally sustains for a period of days, and the average normal wastewater flow is used as the design average flow, and, the sum of peak infiltration/inflow and peak normal wastewater flow can be used as the design peak flow for the sizing of sewers, pumping and treatment facilities. Due to the instantaneous nature of peak inflow, in many cases, it may be more economical to build a flow equalization basin or basins than to design large transportation and treatment facilities.

The estimation of operation and maintenance costs for the transportation and treatment facilities should be based on average, rather than peak, flows. Thus, the total yearly infiltration and inflow, along with the average wastewater flows from domestic, commercial and industrial sources, should be used for such estimation.

(d) Pollutant loadings: The BOD and suspended solids loadings and other pollutants in the infiltration and the inflow are usually low. Their impacts on the secondary treatment processes and the sludge handling processes may not be significant. However, direct inflows entering manholes from perforated manhole covers and defective manhole structures may contain high pollutant loadings, characteristic of those in urban runoffs. The actual pollutant loadings in the infiltration and the inflow can be determinod only by field measurements. Measuring and analyzing the pollutant loadings as well as flows in the sewer system under different groundwater and weather conditions may also reveal the actual loadings contributed from the infiltration and the inflow.

The treatment requirement for each type of pollutant is determined by the effluent limitations set in the NPDES permit(s).

3.4.2.d (2) Cost Estimates - To develop the costs for the transportation and treatment facilities, the reader is referred to the "Guidance for Preparing a Facility Plan" published by EPA in May 1975. [7]

Generally, both capital costs and operation and maintenance costs should be included. The capital costs should include the following items, when appropriate:

- Estimated contract construction costs of all transportation and treatment facilities,
- Costs for engineering services,
- Costs for legal and administrative services,
- Costs of land,
- Startup costs,
- Interest during construction, and
- Contingency allowances.

In addition, the salvage value and revenue produced, if any, should also be included.

3.4.3 Methods of Analysis

The cost-effectiveness analysis can be conducted using one of the following methods.

3.4.3.a Method 1

If, after proper study, the amount of infiltration/inflow removable by corrective action and the required evaluation and rehabilitation work can be determined, a simple cost comparison between the cost required to correct the infiltration/inflow conditions and that required to transport and treat the remaining flow in the system is sufficient to determine whether the infiltration/inflow in the system is possibly excessive. This method normally applies to very small sewer systems or subsystems where estimations of flow and correction work can be made with confidence.

3.4.3.b Method 2

The second method consists of estimating the costs required to remove different percentages of infiltration/inflow from the system and those required to transport and treat the remaining flows. From these costs, two cost curves are plotted, and a total cost curve can be generated by adding the costs on the two plotted curves. (See Figures 3-9 and 3-10.) Examine the total cost curve to locate a minimum cost point. If this cost is less than the total cost corresponding to 0% infiltration/inflow reduction, it can be concluded that possibly excessive infiltration/inflow exists in the system, and the optimum percentage of infiltration/inflow which should be removed is the value corresponding to the minimum total cost point. (Figure 3-9.) From this, the infiltration/inflow which should be included in the design of treatment facilities can also be determined.

Conversely, if the total cost corresponding to 0% infiltration/inflow reduction is the minimum cost point on the curve, it can be concluded that the infiltration/inflow is not excessive. (Figure 3-10.) All infiltration/inflow should be included in facility design.

3.4.3.c Method 3

The third method is more complex. It involves the division of a system into several subsystems. After proper study, all subsystems suspected of having infiltration/inflow problems are selected for the cost-effectiveness analysis. For each selected subsystem, the following are determined:

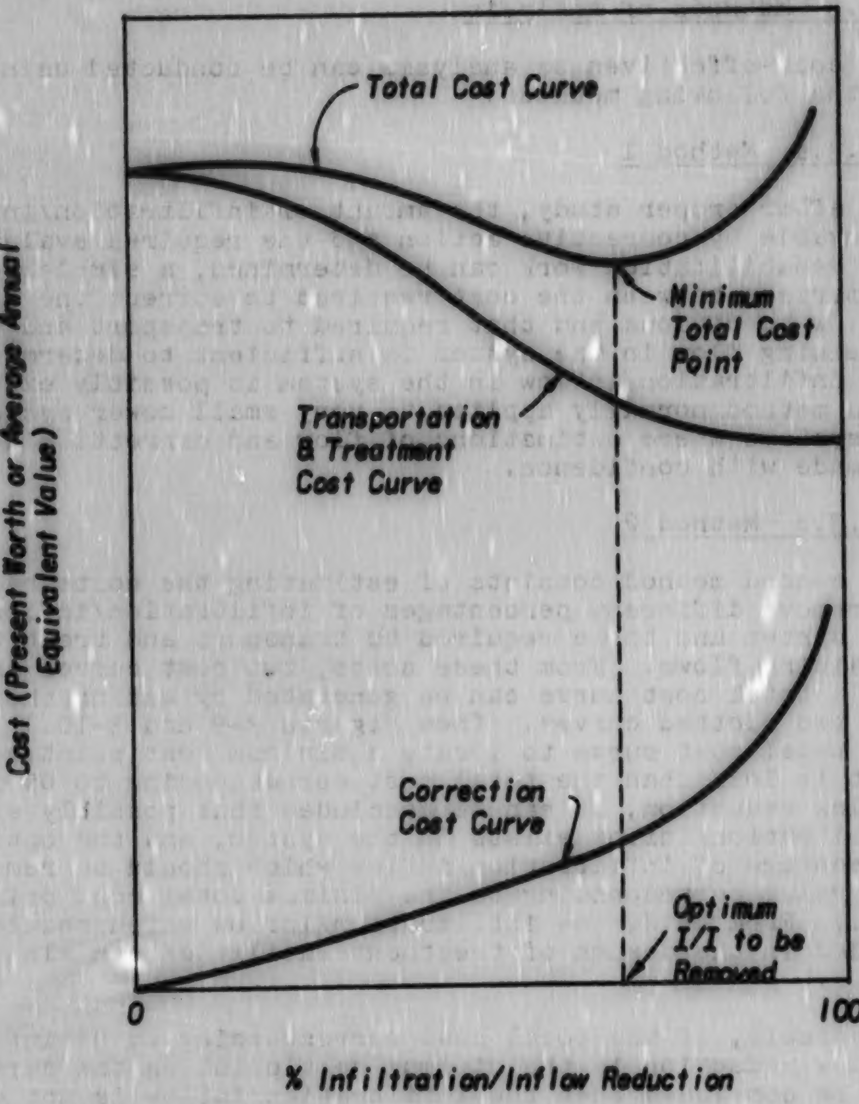

Figure 3-9 Cost-Effectiveness Analysis-Possibly Excessive Infiltration/Inflow (Method 2)

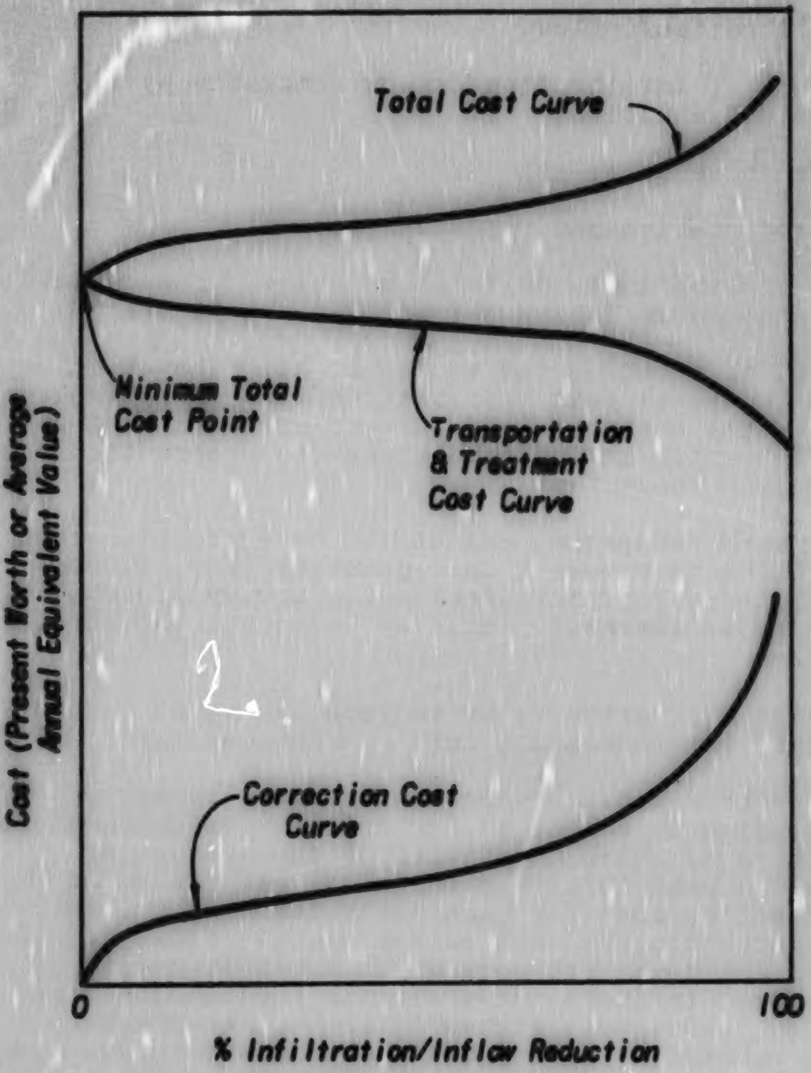

Figure 3-10 Cost-Effectiveness Analysis-Nonexcessive Infiltration/Inflow (Method 2)

(1) Infiltration/inflow;

(2) Amount of infiltration/inflow removable by corrective action;

(3) Corrective cost; and

(4) Transportation and treatment cost.

The procedure for the analysis is shown below. A numerical example is contained in Tables 3-7 and 3-8 and Figure 3-13.

(a) List, in a table, the titles of all subsystems and the total peak infiltration/inflow removable and total cost required for the correction of infiltration/inflow conditions (the correction cost) for each subsystem.

(b) For each subsystem, calculate the correction cost required to remove a unit quantity (say, 1,000 gallons/day) of infiltration/inflow by dividing the total correction cost by the total infiltration/inflow.

(c) Assign a priority value to each subsystem according to the increasing unit correction costs.

(d) In another table, rearrange the subsystems according to the ascending priority values assigned in Step c. List the titles of the subsystems and the peak infiltration/inflow removable and correction cost for each subsystem. Also list, corresponding to each subsystem, the total transportation and treatment cost which would be needed if the peak infiltration/inflow in the subsystem and in all subsystems listed prior to the subsystem are removed from the total flow in the entire system (including both normal wastewater flow and peak infiltration/inflow).

(e) Determine the accumulative peak infiltration/inflow removable, the peak infiltration/inflow remaining and the accumulative correction costs.

(f) Calculate, corresponding to each subsystem, the total flow which would remain in the entire sewer system if the peak infiltration/inflow in the subsystem and in all subsystems listed prior to the subsystem were removed by corrective measures.

(g) Determine the sum of the accumulative correction cost and the total transportation and treatment costs, corresponding to each subsystem, to derive the total cost.

(h) Plot the total cost, corresponding to each subsystem, against the total flow remaining. The total cost for transporting and treating the total flow without infiltration/inflow removal should also be included. Draw a curve passing all the data points. (Figures 3-11 and 3-12.)

(i) Locate on the cost curve a point corresponding to the minimum total cost. If the cost corresponding to this point is less than the cost required to transport and treat the total flow without infiltration/inflow removal, it can be concluded that possibly excessive infiltration/inflow exists in the sewer system (Figure 3-11). The flow corresponding to the minimum cost point is the flow which would remain in the system after an optimal amount of infiltration/inflow is removed from the system. Refer to the table discussed in Step d; all subsystems with total flow remaining greater than the flow corresponding to the minimum cost point should be considered for Sewer System Evaluation Survey and Rehabilitation to correct the infiltration/inflow conditions.

If all costs on the cost curve are found to be greater than the cost required to transport and treat the total flow without infiltration/inflow removal, it can be concluded that the infiltration/inflow in the system is nonexcessive (Figure 3-12).

3.5 ESTABLISHMENT OF POSSIBLY EXCESSIVE OR NONEXCESSIVE INFILTRATION/INFLOW

To determine whether infiltration/inflow is nonexcessive or possibly excessive in a sewer system, a cost-effectiveness analysis is usually conducted (Section 3.4). However, other methods may also be used, for example:

Example: If the sewers in a system were installed according to some specifications which limit the maximum infiltration rate to certain gallons per day per inch diameter per mile of sewer and the actual infiltration/inflow rate in the system is found to be less than that limit, then it can be concluded that the infiltration/inflow in the system is nonexcessive.

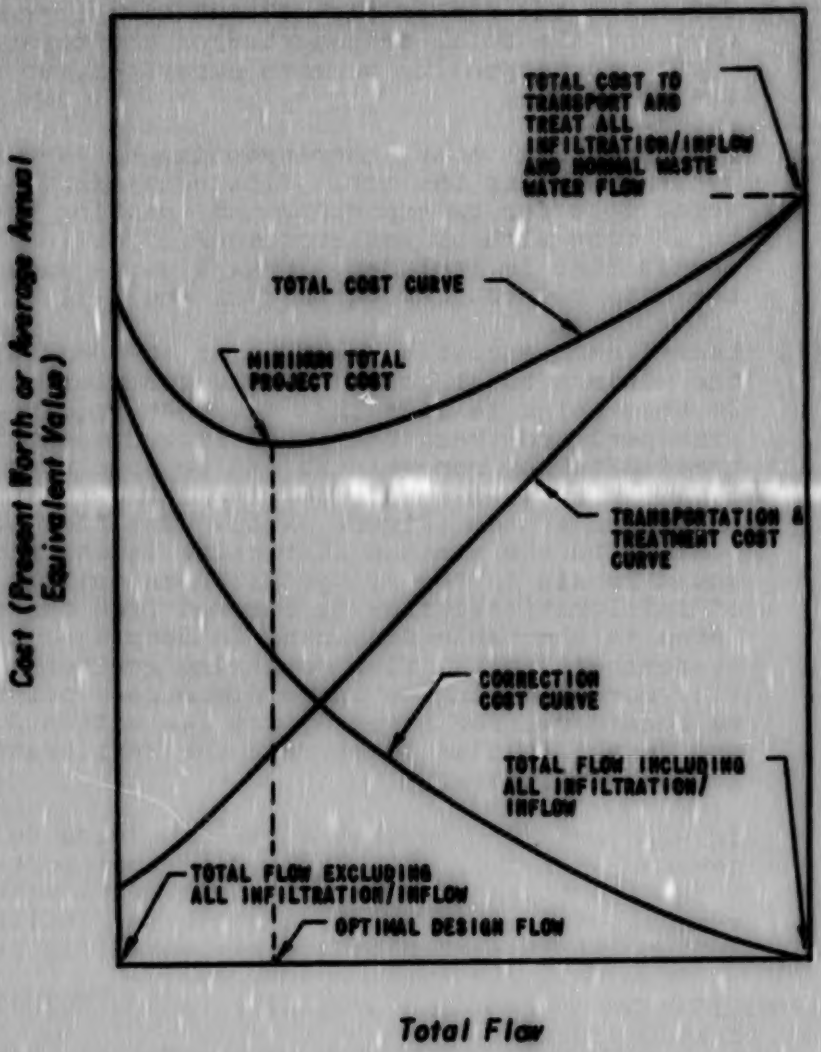

Figure 3-11 Cost-Effectiveness Analysis - Possibly Excessive Infiltration/Inflow (Method 3)

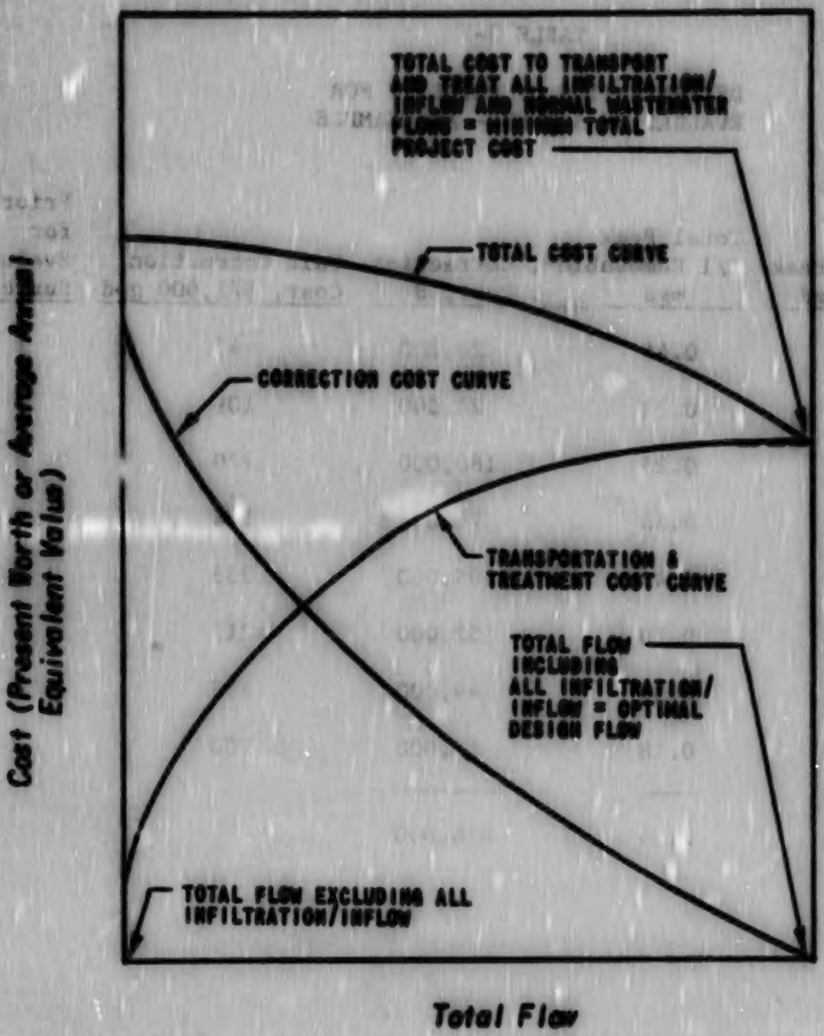

Figure 3-12 Cost-Effectiveness Analysis-Nonexcessive Infiltration/Inflow (Method 3)

TABLE 3-7

DETERMINATION OF PRIORITY FOR EVALUATION SURVEY - AN EXAMPLE

Subsystem	Total Peak I/I, mgd	Total Peak I/I Removable*, mgd	Correction Cost, $	Unit Correction Cost, $/1,000 gpd	Priority for Evaluation Survey
I	0.88	0.44	20,000	45	1
II	0.44	0.22	24,000	109	3
III	0.50	0.25	180,000	720	8
IV	0.76	0.38	70,000	184	5
V	0.90	0.45	105,000	233	7
VI	1.40	0.70	152,000	217	6
VII	0.64	0.32	49,000	153	4
VIII	0.36	0.18	18,000	100	2
	5.88	2.94	618,000		

*For the purpose of this example it is assumed that 50% of the I/I can be removed from each subsystem.

TABLE 3-8

DETERMINATION OF COSTS - AN EXAMPLE

Subsystem	Total Peak I/I Removable, mgd	Accumulative Total Peak I/I Removable, mgd	Total Peak I/I Remaining[1], mgd	Total Flow Remaining[2], mgd	Correction Cost, $	Accumulative Correction Cost, $	Transportation & Treatment Cost,[3] $	Total Cost, $
			5.88	8.88	0	0	5,030,000	5,030,000
I	0.44	0.44	5.44	8.44	20,000	20,000	4,961,000	4,981,000
VIII	0.18	0.62	5.26	8.26	18,000	38,000	4,940,000	4,978,000
II	0.22	0.84	5.04	8.04	24,000	62,000	4,900,000	4,962,000
VII	0.32	1.16	4.72	7.72	49,000	111,000	4,860,000	4,971,000
IV	0.38	1.54	4.34	7.34	70,000	181,000	4,830,000	5,011,000
VI	0.70	2.24	3.64	6.64	152,000	333,000	4,700,000	5,033,000
V	0.45	2.69	3.19	6.19	105,000	438,000	4,630,000	5,068,000
III	0.25	2.94	2.94	5.94	180,000	618,000	4,600,000	5,218,000

[1] Total peak I/I in system is 5.88 mgd.

[2] Average wastewater production (3.0 mgd) plus total peak I/I remaining.

[3] Present worth of all costs.

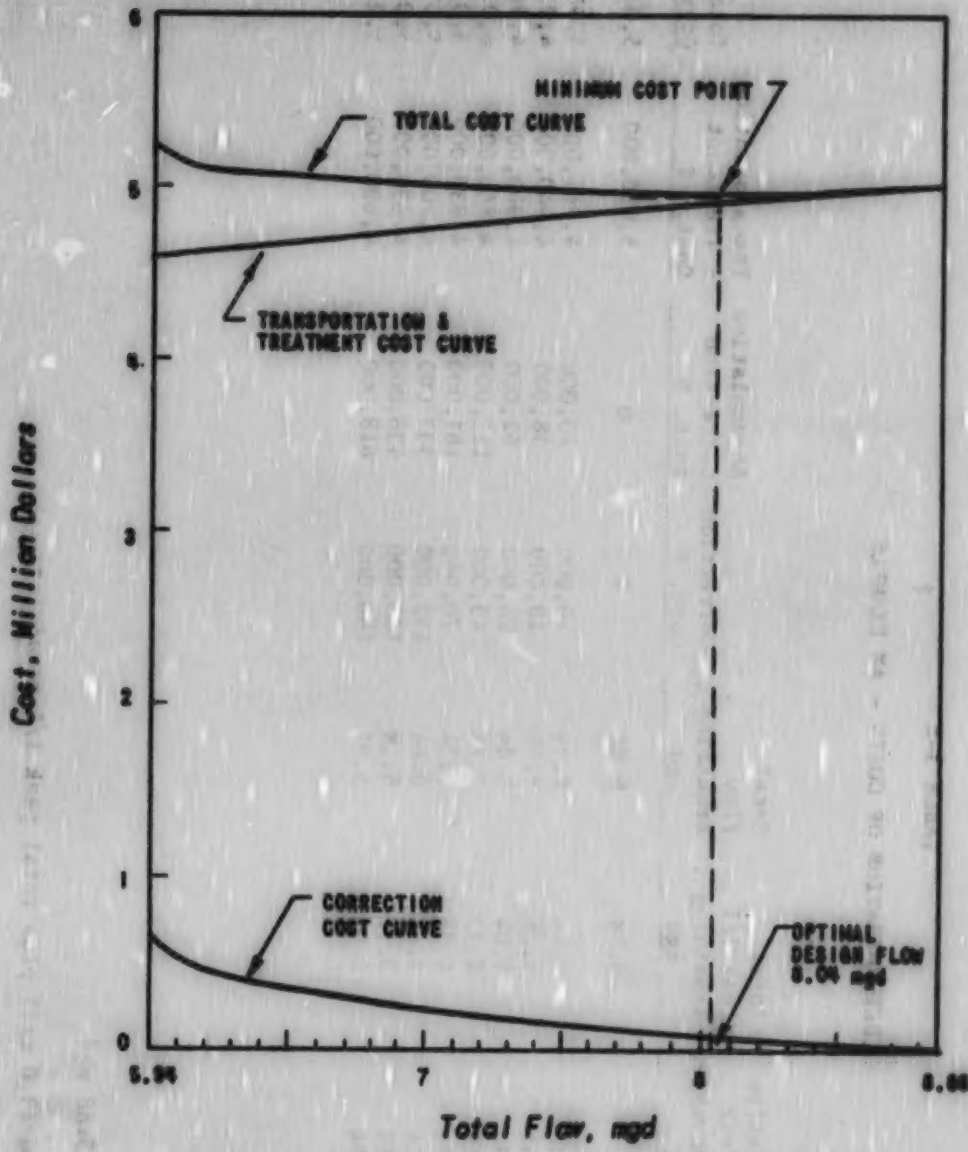

Figure 3-13 Determination of Optimal Design Flow - An Example

If the infiltration rate alone is found to be less than that limit, then it can be concluded that the infiltration in the system is nonexcessive. To determine whether inflow is also nonexcessive, other methods, such as cost-effectiveness analysis, may still have to be used.

If the infiltration rate in any subsystem is found to be less than that limit, it can be concluded that the infiltration in that particular subsystem is nonexcessive. All subsystems which show nonexcessive infiltration should be eliminated from further infiltration study. If eventually a cost-effectiveness analysis is to be conducted, the survey and rehabilitation costs for the sewers in such subsystems should not be included except for those costs related to inflow study.

The rationale behind the above determinations is that if the sewers were installed according to a certain specification, the material and workmanship used for the construction were designed to meet that specification and one should not expect to obtain a sewer better than that. If more is expected, the entire system may have to be rehabilitated. There are instances, however, where sewers were installed with opened joints to serve as area drains; these sewers could be rehabilitated to attain a tighter sewer system than when originally installed.

3.6 SEWER SYSTEM EVALUATION SURVEY PROGRAM RECOMMENDATION

Having established that infiltration/inflow is possibly excessive in a sewer system, a recommended program that will culminate in the solution of the problem should be presented. For conducting a systematic examination of the sewer system to determine the specific location, flow rate and rehabilitation costs of the infiltration/inflow problem, the following five phases of work are usually recommended:

- Physical survey
- Rainfall simulation
- Preparatory cleaning
- Internal inspection
- Preparation of report

Because of the different nature of the problems in the sewer systems, the required work may vary among projects. The sequence of carrying out these five phases of work may also vary among projects. All five phases of work need not be included in the program if not necessary. The purpose of the Evaluation Survey is to continually redefine the problem areas of the sewer systems. For each phase of work recommended, the following details should usually be included:

- The specific areas to be studied;
- The functions to be performed and their purposes;
- The recommended method or methods for performing each function;
- The manpower, materials and equipment and the time duration required to perform each function; and
- The costs required to complete each phase of work.

Finally, a project schedule should be set up for the performance of all the recommended work within the allowable time limit.

3.6.1 Program Recommendation

An outline of all the possible functions which may be included in each phase of the Sewer System Evaluation Survey is presented in the following subsections. These functions should be evaluated with discretion. Only those functions found necessary should be included in the recommended evaluation survey program. The method(s) to be recommended for performing each of the required functions should be determined by the conditions of each individual system. (See Chapter 4 for more details.)

3.6.1.a Physical Survey

The purpose of the physical survey is to determine the flow characteristics, groundwater levels, physical conditions of the sewer system and the possible infiltration and inflow sources, and to reduce the study areas for cleaning and internal inspection. The functions that may be included in the physical survey are:

- Flow monitoring in key manholes to isolate problem areas;

- Groundwater monitoring at key manholes or along routes of problem sewers;
- Physical inspection of the manholes and the sewers;
- Searching for possible cross-connections between storm sewers and sanitary sewers;
- Searching for low manholes;
- House to house search for possible inflow sources such as roof leader, cellar, yard and area drains, foundation drains, sump pump connections, cooling water discharges, etc; and
- Searching for inflow sources from springs and swampy areas.

The areas to be surveyed can be initially determined through a careful study of the data collected during the I/I Analysis. Areas with no obvious infiltration/inflow problems should not be recommended for survey. If the cost-effectiveness analysis is conducted for each individual subsystem, the subsystems with nonexcessive infiltration/inflow should also be excluded from further investigation.

3.6.1.b Rainfall Simulation

The rainfall simulation is used to identify sections of sewer lines which have infiltration/inflow conditions during periods of surface runoff. The following conditions can be identified by rainfall simulation:

- Cross-connections between storm sewers and sanitary sewers, or between catch basins and sanitary sewers;
- Inflow sources, such as streams, open ditches, ponding areas, etc., which contribute clean water to the sanitary sewers during dry or wet weather conditions;
- Inflow sources in residential and commercial areas such as roof leader, cellar, yard and area drains, foundation drains, cooling water discharges, etc; and
- Low-lying manholes which receive surface runoffs during storm periods.

The locations where rainfall simulation studies are to be conducted can be preliminarily determined by reviewing the results from the interviews, map analysis and field observations. Results from the physical survey may further help pinpoint these locations.

The rainfall simulation techniques usually applied are:

- Smoke testing
- Dyed water flooding
- Water flooding

3.6.1.c Preparatory Cleaning

The preparatory cleaning is needed to prepare the sewer lines for unobstructed internal inspection. It is usually recommended for the sections of the sewer lines which are to be internally inspected unless studies show that the lines are sufficiently clean for the inspection technique(s) to be recommended. Sewers can be cleaned by a number of methods, depending on the type and degree of deposition and the sizes of the pipes. The degree of cleaning required can be preliminarily estimated by reviewing the results from interviews and from observations in key manholes during flow measurements. Sewers in municipalities having good sewer maintenance programs usually require less cleaning than those in municipalities having poor maintenance programs.

3.6.1.d Internal Inspection

The internal inspection is performed to determine the specific location, condition and estimated flow rate of each source of infiltration/inflow defined in the selected sewer sections. Inspection by television is usually recommended; however, other available methods can also be utilized, if suitable. Internal inspection should be performed during periods of maximum groundwater levels. To simulate rainfall conditions, storm sewer sections, stream sections, ditch sections, and ponding areas related to infiltration/inflow conditions should be flooded during the inspection. Alternatively, the inspection can be conducted during heavy rainfall periods. In some systems, because of the area where they are located, it is essential to conduct internal inspection during rains.

3.6.1.e Preparation of Report

After the previous four phases of the Sewer System Evaluation Survey are completed, a report should be prepared to summarize all the findings. The following information is usually included in the report:

- A complete documentation of all the information gathered during the evaluation survey;
- A justification for each sewer section cleaned and internally inspected;
- A cost-effectiveness analysis to determine the sewer sections which can be cost-effectively rehabilitated to remove the infiltration/inflow;
- A proposed rehabilitation program to eliminate all defined excessive infiltration/inflow.

3.6.2 Cost Estimates

The costs required to accomplish each phase of the work described above should be estimated. For cost estimation, the functions to be performed during each phase should be first listed. Difficulty factors involved and manpower and equipment required for each function can be evaluated on the basis of available information. The cost related to each function should be determined.

3.6.3 Project Schedule

To accomplish all the work required for the Sewer System Evaluation Survey in an allotted time limit with lowest possible costs, a realistic project schedule should be established. The time limit is determined by the overall schedule outlined in the facilities plans, which should meet the schedule stated in the discharge permit issued by the regulatory agencies. In some instances, however, the required work may only be realistically achievable by a long-range program. This type of situation should be discussed with State and EPA Officials and a workable solution developed. In order to obtain meaningful information, the studies should always be conducted under most favorable ground water and weather conditions. The sequence of carrying out the different phases of the work is determined by the conditions in the sewer systems and the availability of manpower and equipment for the specific job.

CHAPTER 4

SEWER SYSTEM EVALUATION SURVEY

4.1 INTRODUCTION

The Sewer System Evaluation Survey is a systematic examination of the sewer system to locate all the infiltration and inflow sources which were previously determined to be possibly excessive, determine the flow rate from each source and estimate the costs required for the rehabilitation of the system. The following tasks are usually included in the evaluation survey:

- Physical Survey
- Rainfall Simulation
- Preparatory Cleaning
- Internal Inspection
- Survey Report

The tasks are not necessarily performed in the order in which they are presented.

The physical survey is performed to isolate the problem areas and to determine the general physical conditions of the sewer sections selected for further study. The rainfall simulation is conducted to locate the rainfall associated infiltration/inflow sources in the sewer system. Preparatory cleaning is needed to prepare the sewer lines for internal inspection, which determines the infiltration/inflow sources, the flow rate from each source and the structural defects in the pipes. The survey report summarizes the results obtained during the survey and presents a cost-effectiveness analysis which determines the portion of the infiltration/inflow sources which can be economically corrected.

To perform all these tasks in as short a period of time as possible, proper planning is essential. The physical survey is usually performed during the high groundwater period, so is the internal inspection. However, the physical survey is normally performed before the internal inspection. In order to complete both tasks in the same high groundwater season, the physical survey, rainfall simulation, if required, and preparatory cleaning should be conducted as rapidly as possible. To shorten the total study period, the rainfall simulation can be performed concurrently with the physical survey, the preparatory cleaning or internal inspection.

The preparatory cleaning and internal inspection normally demand much more time than other tasks. However, all sewer systems do not require internal inspection. Before proceeding to the preparatory cleaning and internal inspection, the results from the physical survey should be carefully analyzed. If the infiltration/inflow sources can be located and quantified during the physical survey, no internal inspection will be needed. This may be the case if the infiltration/inflow sources are located in the manholes or near both ends of the sewer lines. To minimize both the time and the cost for the study, all efforts should be made to eliminate as many sewer sections from internal inspection as possible.

4.2 PHYSICAL SURVEY

4.2.1 General

The physical survey involves all the tasks which are required to accomplish the following objectives:

(a) Identify the segments of the sewer system which may require further study;

(b) Determine the general physical conditions of the manholes and sewer lines in the selected segments of the sewer system; and

(c) Compile the background information required for the planning of the subsequent studies.

The following tasks are normally included in the physical survey:

(a) Aboveground inspection,

(b) Flow monitoring, and

(c) Manhole and sewer inspection.

After the completion of a physical survey, a report may be prepared. This report is required by some states. The report summarizes all the data collected during the survey and provides justification for:

(a) The sewer sections recommended for internal inspection.

(b) The degree of cleaning required for each sewer section recommended for internal inspection.

(c) The location and sewer sections where rainfall simulation should be conducted.

4.2.2 Aboveground Inspection

The aboveground inspection is conducted to accomplish the following objectives:

(a) Investigate the general conditions of the study area, such as topography, streets, alleys, access to manholes, etc.;

(b) Locate potential problem areas, such as waterways, river crossings, natural ponding areas, etc.; and

(c) Select the key manholes for additional flow measurement and groundwater monitoring.

Conducted by a trained observer, valuable information can be obtained which would facilitate the planning of other tasks in the evaluation survey.

However, if sufficient information has been gathered during the Infiltration/Inflow Analysis, this task may not be necessary.

4.2.3 Flow Monitoring

The purpose of flow monitoring is to locate and isolate the areas where infiltration/inflow problems exist. Generally, portions of the system pose no problem; therefore, they will be eliminated from further study. This task should be accomplished at the earliest possible stage in order to minimize the survey costs.

In the analysis phase of the study, the flow monitoring work has already been performed in a few selected key manholes. All subsystems which present no infiltration/inflow problems are eliminated from further study in the evaluation survey. The additional flow monitoring work performed during the physical survey is actually a continued effort to further reduce the number of areas to be investigated.

The flow monitoring is usually conducted in a number of selected key manholes. The flows should be monitored during the highest groundwater level period. Both dry weather high groundwater and wet weather high groundwater flows should be monitored to determine the magnitude of inflow as well as of infiltration in each subsystem. To minimize the interferences caused by the normal wastewater flows, the flow monitoring is usually conducted during the early morning hours. However, on large systems early morning flows may be substantial because of continuous discharges to the sewers and lag time of flow due to the length of sewers.

For detailed information regarding the procedures for selecting key manholes, the methods and equipment used, the safety measures, and other pertinent considerations, see Section 3.2.6.

4.2.4 Manhole and Sewer Inspection

4.2.4.a General

The manhole and sewer inspection is a task to determine the actual physical condition of the sewer system. The data generated from the inspection would be valuable for the identification of infiltration/inflow sources. It also provides a factual base for the establishment of a preparatory cleaning program for internal inspection and a routine sewer maintenance program.

The inspection can be started after all the problem areas have been isolated through a flow monitoring program. It may also be conducted concurrently with the flow monitoring program to accelerate the evaluation survey.

All the manholes and sewer lines in the designated problem areas of the sewer system should be included in the inspection. Each manhole should be entered. The manhole and the sewer pipes connected to it should be inspected carefully to determine the physical conditions, infiltration/inflow sources, type and degree of deposition and other special problems and conditions.

4.2.4.b Time for Inspection

The manhole and sewer inspection is usually performed during the high groundwater period, for, during this period, the groundwater-associated infiltration/inflow sources can be easily detected. The inspection can be performed during either dry weather high groundwater or wet weather high groundwater conditions. But it is more convenient to do it in the dry weather as the flows in the sewers during dry weather are lower and the physical conditions of the manhole and the sewers can be checked more easily. The inspection is normally conducted during the daytime, at the hours when the wastewater flows are low, if possible.

4.2.4.c Preparation

Before the inspection is started, a complete sewer map of all the manholes and sewer lines to be inspected should be prepared. The manholes should be properly numbered for easy identification. The equipment which is needed for manhole and sewer inspection includes:

- Personal safety equipment
- Portable lamps
- Hand-held mirrors
- Ruler
- Thermometer
- Other equipment

Manhole entering imposes potential safety and health hazards. The personal safety equipment should always be carried and used in the field. The safety equipment required for manhole entering is presented in Section 3.2.6.d. All the safety measures discussed in that section should also be followed closely.

The hand-held mirror and the portable lamp are used to lamp the sewer lines for easy inspection. The lamp should be flameless to avoid accidental explosion of the gases in the sewers. The commonly used flashlights are sufficient for such purpose.

The ruler is used to measure the dimensions and the water depths in the sewers and manholes. The thermometer is used to measure the temperature of the flow in the pipe. Equipment for the determination of conductivity, sulfate, fluoride or other constituents in sewage may also be needed in some cases.

4.2.4.d Procedure

4.2.4.d (1) Manhole Inspection - The manhole inspection involves the observation and recording of the following information in each manhole:

(a) Manhole identification;

(b) Construction materials and conditions of cover, ring, corbel work, walls, steps, aprons and troughs;

(c) Manhole depth and opening size;

(d) Number and size of holes, if any, in manhole cover;

(e) Visible infiltration sources and estimated flow rates;

(f) Evidence of leaks and location;

(g) Level of high water mark in the manhole;

(h) Type and depth of debris;

(i) Groundwater level at the manhole, if monitored; and

(j) Special problems and conditions, such as sources of inflow, overflows, bypasses, manholes located in natural ponding areas, etc.

A typical data sheet used to record the above information during manhole inspection is shown in Table 4-1.

For manholes which cannot be inspected because of, say, inability to locate, inability to open, surcharged, no steps, etc., the reasons should be recorded.

4.2.4.d (2) Sewer Inspection - After the inspection of a manhole is finished, the incoming and outgoing sewer lines connected to the manhole are inspected in turn. The sewers are inspected by lamping the line both at the manhole being inspected and at the manhole down the line. By lamping at both ends of the pipe, a greater visibility can be achieved. A mirror is used to deflect the light from the lamp to different parts of the pipe for close inspection. The following information is usually recorded:

(a) Length, size, type and depth of pipe;

(b) Depth and temperature of flow;

(c) Other parameters in sewage such as conductivity, sulfate concentration, fluoride concentration, etc.

(d) Root growth in pipe;

(e) Type and depth of deposition in pipe and recommended cleaning method;

(f) Visible infiltration/inflow sources;

(g) Structural condition of pipe; and

(h) Special problems and conditions in pipe.

A sketch showing the relative locations of the manholes and the pipelines should also be included in the data sheet. Table 4-2 shows a typical data sheet for sewer inspection.

TABLE 4-1 TYPICAL DATA SHEET FOR MANHOLE INSPECTION

MH#________ Location______________________________ Drainage Area__________

Project:____________________________________ Project No.________________

Client____

Date____/____/______ Time__________ a.m. p.m. Inspector________________

Weather: No rain________; rain____; snow____

A. INVENTORY

Item	Construction Material	Condition		
		Good	Fair	Poor
Cover				
Ring (frame)				
Steps				
Corbel Work				
Walls				
Aprons				
Troughs				

B. OBSERVATIONS

1. Diameter of manhole opening ____ in.
2. Holes in cover ___; number ____; size __________ in.
3. Visible infiltration through joints, cracks, lines, etc., height above sewer invert, estimated flow rates________
   ____
   ____
4. Evidence of leaks in manhole, height above sewer invert
   ____
   ____
5. High water marks in manhole, height above sewer invert, possible cause ______________________________________
   ____
6. Manhole has ___ does not have ___ ground water level gauge ground water level above sewer invert ____________
7. Debris: No___; yes ___, type_________, depth ___ in.
8. Special problems, conditions, sources of inflow, overflows, bypasses.
   ____
   ____
   ____

TABLE 4-2 TYPICAL DATA SHEET FOR SEWER INSPECTION

MH#______ Location__________________ Drainage Area________

Project:________________________ Project No.____________

Client:____

Date:___/___/___, Time______________ a.m. p.m. Inspector__________

Weather: No rain; rain_______; snow_________

Pipe Data	Incoming Lines			Outgoing lines
	From MH #__ Distance _____ ft	From MH#__ Distance ________ ft	From MH#__ Distance ________ ft	To MH#__ Distance
Pipe Sizes, in.				
Type of Pipe				
Depth from MH Top to Invert				
Depth of Flow, in.				
Temperature of Flow, °F				
Conductivity of Sewage, mho/cm				
Sulfate Concentration, ppm				
Fluoride Concentration, ppm				
Root Growth in Pipe				
Type of Deposition				
Depth of Deposition, in.				
Recommended Cleaning Method				
Visible Infiltration/Inflow Sources in Pipe				
Structural Conditions of Pipe				
Special Problems and Conditions				

Sketch of Manholes and Sewers:

An inventory of the length, size, type, depth and the general conditions of the sewer pipes would provide a basis for the estimation of the amount of work required for the preparatory cleaning and internal inspection. It also provides a basis for sewer rehabilitation work and routine sewer maintenance.

The depth of flow would provide a rough indication about the capacity and/or structural condition of the sewer pipe and indicate if infiltration/inflow is present in the sewer section. For example, a surcharged line under normal conditions may indicate a deficiency in pipe capacity or the existence of some infiltration/inflow sources along the pipe.

The flow temperature may also be used as an indicator for the detection of the extraneous water entering the sewer section being investigated. Thus, if the measured flow temperature is much higher or lower than the average sewage temperature measured in the upstream manholes and there is no discharge from the service connections at the time of measurement, there are definitely some infiltration/inflow sources along the sewer pipe. Similarly, the conductivity, the sulfate concentration and the fluoride concentration in the sewage may also be used to detect the infiltration/inflow sources.

The root growth condition and the type and depth of deposition in the pipe would dictate the selection of the methods for the root control and for the sewer cleaning before internal inspection. An experienced sewer inspector should be able to judge the condition in the field and recommend the best cleaning method for each section of pipe. (The commonly used cleaning methods are presented in Section 4.4.)

All visible infiltration/inflow sources should be recorded. Each sewer line is actually inspected from two different manholes. This provides a chance to detect any infiltration/inflow sources and/or structural defects which are undetectable from only one end of the pipe.

The structural condition of the sewer pipe should also be recorded. All structural defects and other unusual conditions, such as cave-ins, crushed pipes, cracks, signs of deterioration, horizontal misalignments (kicked joints), vertical misalignments (dropped joints), sags, open joints, protruding taps, missing pipes, etc., should also be recorded.

The physical survey is most effectively conducted during high groundwater periods, thus an additional task which should be performed is measurement of the groundwater depth. (See Section 3.2.4.d for details.)

4.2.5 Report

The main purpose of preparing a report at the end of the physical survey is to provide a document to justify all the subsequent work required in the evaluation survey. This report is required by some states. After finishing all the tasks in the physical survey, the general conditions in the sewer system are clear to the investigator. A judgment should be possible at this stage as to what sections of sewer lines should be further studied, which lines would need preparatory cleaning before internal inspection, what are the justifications for the cleaning and for the inspection, and where and how the rainfall simulation should be conducted.

The sewer lines located in the subsystems which are found from the flow monitoring program to have possibly excessive infiltration/inflow are generally recommended for further investigation. The lines which need preparatory cleaning are those which have deposition of any kind which may interfere with the internal inspection. The degree of cleaning (light cleaning or heavy cleaning) and the recommended cleaning equipment can be determined on the basis of the degree and type of deposition, and the structural conditions and accessibility of the sewers to be inspected. The inspection method to be recommended would depend on type of information required, pipe size and internal conditions.

The areas where the rainfall simulation should be conducted are those which show infiltration/inflow conditions during rainfall periods. The method to be recommended for the simulation would depend on the type of infiltration/inflow source expected and other conditions in the sewer system and the study area.

4.3 RAINFALL SIMULATION

4.3.1 General

The rainfall simulation techniques are utilized to identify sections of sewers which have infiltration/inflow conditions during rainfall periods. Generally these techniques are only employed on separate sewer systems since combined systems were designed to collect some inflow.

The infiltration/inflow sources which can be identified by the rainfall simulation techniques include:

(a) Roof leader, cellar, yard and area drains and foundation drains;

(b) Abandoned building sewers, faulty connections and illegal connections;

(c) Cross-connections between sanitary sewers and storm sewers;

(d) Storm sewer sections, stream sections, ditch sections and ponding areas which may cause infiltration/inflow in sanitary sewers; and

(e) Structurally damaged sewers and manholes.

Although a convenient tool, rainfall simulation does not have to be performed in every sewer system evaluation study. A careful study of the sewer maps and reviews of the Infiltration/Inflow Analysis report and the physical survey results would indicate whether rainfall simulation is needed and, if so, where it should be applied and what techniques should be used. The following are the situations where rainfall simulation may be considered:

(a) Storm sewer sections which parallel or cross sanitary sewer sections (including service connections) and have crown elevations greater than the invert elevations of the sanitary sewers may be potential infiltration/inflow sources. If the sanitary sewer sections which parallel or cross such storm sewer sections show excessive infiltration/inflow and there are no other conceivable or detectable infiltration/inflow sources, the rainfall simulation techniques may be considered.

(b) Stream sections, ditch sections and ponding areas located near or above sanitary sewer sections may also be potential infiltration/inflow sources. The rainfall simulation techniques may also be utilized to identify such sources for sewer sections which show excessive infiltration/inflow if no other sources are conceivable or detectable.

(c) Roof leader, cellar, yard and area drains and foundation drains, abandoned building sewers, faulty connections and illegal connections which are suspected to exist but cannot be identified by other means during the physical survey may be detected by the rainfall simulation techniques.

Besides being an identification tool, rainfall simulation can also be utilized in conjunction with flow measurements to quantify the infiltration/inflow from each of the identified sources.

The rainfall simulation techniques may be utilized to estimate the quantity of infiltration/inflow that may reach the sewer lines under unpaved areas, particularly service lines. However, although rainfall may be simulated in small areas, it is often almost impossible to simulate actual wet weather conditions. Flow measurements performed during actual wet weather conditions usually provide data which are more meaningful than those gathered under the simulation rainfall conditions.

Many of the tests are performed on private properties. It is essential to obtain full cooperation of the property owners. Before the tests, the owners should be notified and the nature of the tests should be explained to them.

The rainfall simulation techniques commonly used are:

- Smoke testing
- Dyed water testing
- Water flooding test

In the following sections, details of these techniques are presented.

4.3.2 Smoke Testing

4.3.2.a Application and Limitations

Smoke testing is an inexpensive and quick method of detecting infiltration/inflow sources in sewer systems. The method is best used to detect inflow sources such as roof leader, cellar, yard and area drains, foundation drains, abandoned building sewers, faulty connections, illegal connections and storm sewer cross connections. It can also be utilized to detect the structural damages and leaking joints in sewer pipes and the overflow points in the sewer systems.

The method is only a detecting technique and cannot be used to quantify the flows. To accomplish the latter, one should measure flows in the sewer sections which are found by the smoke testing to have infiltration/inflow conditions. The flow measurements can be performed during the wet weather conditions or during the simulated rainfall conditions.

If reliable information is to be derived from smoke testing, the method should not be applied to the sewer lines which contain water traps or sags. Both of these two pipe conditions may prevent the smoke from passing through and result in false conclusions. Similarly, the methods should not be applied to sewer sections that are flowing full. The method cannot be utilized to detect the structural damages and leaking joints in buried sewers and service connections when the soils surrounding and above the pipes are saturated, frozen or snow covered. In each case, the smoke will be trapped and will not come out of the ground even though there are cracks or leaking joints in the pipes. Rain and snowy days are not suitable for smoke testing. The test should not be performed on windy days when the smoke coming out of the ground may be blown away so quickly as to escape visual detection.

Because of the many unknowns in the sewer systems and the uncertainties about the soil and groundwater conditions, the results from smoke testing should be analyzed carefully. The positive findings during the tests definitely indicate the existence of the infiltration/inflow sources. The negative findings, however, may not prove that the problems do not exist. Whenever the results from the smoke testing are in doubt, the more positive detection method, i.e., the dyed water testing, may be tried, or observations conducted during wet weather.

The method normally does not cause safety or health hazards. It is usually performed above the ground and no manhole entering is necessary. However, because of possible confusion resulting from smoke appearing in and around dwellings, the public should be notified prior to the test and the local fire department should also be informed. A typical smoke testing, between two manholes, usually takes about 10 to 15 minutes. More time will be needed under unusual sewer and manhole conditions.

4.3.2.b Equipment

The following equipment is usually needed to conduct smoke testing:

- Smoke bombs
- Air blower
- Camera and film
- Sand bags and/or plugs

The smoke bombs are used to generate the smoke required for the test. The smoke should be nontoxic, odorless and nonstaining. The 3-minute and 5-minute bombs are normally used although bombs which can last longer or shorter are also available. The air blower is used to force the smoke into the sewer pipes. A gasoline-driven blower is most convenient for this purpose. The air blower should have a minimum capacity of about 1500 CFM. The camera is used to take the pictures of the smoke coming out of the ground, catch basins, pipes and other sources during the test. The photographs are taken for permanent documentation of the infiltration/inflow sources. The sand bags and/or plugs are used to block the sewer sections to prevent the smoke from escaping through the manholes and adjacent sewer pipes.

The smoke bomb and the air blower are usually set up aboveground near the manhole to be tested.

4.3.2.c Procedure

The following procedures are normally followed to perform the smoke testing:

(1) Preparation for the test

(a) Determine the sewer sections where the smoke tests are to be performed. Locate the sewer sections and manholes. Check the manholes for accessibility and check the flow conditions in the sewer pipes. Make provisions for flow bypassing, if necessary.

(b) Determine the time for the tests. Avoid rainy, snowy and windy days. Schedule the test for the period when the groundwater levels are low and the ground is not snow covered.

(c) Notify the residents in the areas where the tests are to be performed regarding the nature and time of the test. Also notify the local fire department.

(2) Test procedure

(a) Usually two manhole sections are tested simultaneously. Set up the equipment at the intermediate manhole of the sewer sections to be tested. The smoke is usually introduced into the sanitary sewer sections, even for the detection of the cross-connections between storm sewers and sanitary sewers.

(b) Partially plug the sewer lines at the far ends with sand bags or plugs. The sand bags or plugs are attached with ropes to facilitate lowering and retrieving from above the manhole.

(c) Ignite the smoke bomb and force the smoke into the sewer section with the blower. The supply of smoke should be continuous until the area serviced by the test sections is thoroughly examined and all problems recorded.

(d) Observe the appearance of the smoke coming out of the ground, storm sewer, catch basins, roof drains, abandoned building sewers, etc. Record the observations with the camera. Mark down on the back of the photographs, or on a log sheet, the dates, locations and situations of the results.

4.3.3 Dyed Water Testing

4.3.3.a Application and Limitations

The dyed water testing is usually used to determine whether the storm sewer sections, stream sections, ditch sections and/or ponding areas which are located near or above the sanitary sewer sections are contributing any infiltration/inflow to the sanitary sewers. The method can also be utilized to detect the other infiltration/inflow sources listed in Section 4.3.1. It can be used to check the results from the smoke testing. Under unfavorable weather, groundwater, soil, sewer structure and/or flow conditions, the dyed water testing can be utilized to substitute for the smoke testing to obtain more reliable information. Quantification of the flows is possible when the dyed water testing method is used to identify the infiltration/inflow sources.

The method, however, is usually more expensive and time-consuming than the smoke testing technique. It is also limited to locations where large quantities of water are available for the test. Manholes and storm sewers may have to be entered for the test; therefore always be safety conscious.

4.3.3.b Equipment

The equipment needed for the dyed water testing is limited to that required to carry the water to the testing site and to block the sewers or the study areas before the testing.

When fire hydrants are close to the sewer sections to be tested, a fire hose is all that is needed to deliver the water to the testing site. On the other hand, when the water source is not close by, water tankers will be required to deliver the water. Sand bags or sewer pipe plugs are normally used to block the sewer sections.

The fluorescent dyes are usually used for the test. Each dye has a distinct color which is readily detectable by eye. A suitable dye should be safe to handle, visible in low concentrations, miscible in water, inert to the soils and the debris in the sewers and biodegradable. (Typical dyes available for this purpose are listed in Table 3-2.)

4.3.3.c Procedures

Depending on the infiltration and inflow sources to be identified, the procedures for the dyed water testing differ.

4.3.3.c (1) Determination of Infiltration/Inflow Conditions Caused by Storm Sewer Sections - The storm sewer sections which parallel or cross sanitary sewer sections and have crown elevations greater than the invert elevations of the sanitary sewers can be either infiltration sources or inflow sources. They are inflow sources if there are cross-connections between the storm sewer sections and sanitary sewers. They are infiltration sources if the storm water can exfiltrate from them, percolate through the soil and enter the sanitary sewers through pipe defects, broken pipes and/or leaking joints. The dyed water testing can be used to detect both of these possibilities. To differentiate between the two, an analysis of the percolative capacity of soil is necessary in addition to the determinations of the presence, concentration, flow rate, and travel time of the dyed water entering the sanitary sewers. A careful analysis of these factors would also enable one to locate the sources and quantities of infiltration/inflow. If the technique is to be used merely to determine whether cross-connections are existing between the sanitary sewers and the storm sewers or catch basins, then it is only necessary to determine the presence and travel time of the dyed water into the sanitary sewers.

The general procedures for dyed water testing in storm sewer sections are as follows:

(a) Plug both ends of the storm sewer section to be tested with sand bags or other materials. Block all the overflow and bypass points in the sewer section. Provide bypassing of flow, if necessary.

(b) Fill the storm sewer section with water from fire hydrants or other nearby water sources. Add dye to the water.

(c) Monitor the downstream manhole of the sanitary sewer system for evidence of dyed water. Determine the time of travel and, if desired, the concentration of the dyed water.

(d) Measure the flows in the manhole before and during the dyed water testing. As an alternative, the flows can be simultaneously measured at both the upstream and downstream manholes during the test.

(e) Record the location of storm and sanitary sewer lines being tested, the time and duration of tests, the manholes where the flows are monitored and the flow rates, the observed presence, concentrations and travel time of the dyed water into the flow monitoring manholes, and the soil characteristics.

4.3.3.c (2) Determination of Infiltration/Inflow Conditions Caused by Stream Sections, Ditch Sections and Ponding Areas - To determine whether the stream sections, ditch sections and ponding areas located near or above sanitary sewer sections are causing infiltration/inflow conditions in the sanitary sewers, the procedure similar to that described in the previous section is recommended. In these cases, the stream sections, ditch sections and pond areas to be tested should be plugged or dammed and filled with dyed water to the desired levels. The presence, concentration and/or travel time of the dyed water into the sanitary sewers are then monitored in the downstream manholes. The flow rates can be monitored if necessary. The percolative capacity of the soil can be determined to facilitate the estimation of the sources and quantities of infiltration/inflow.

4.3.3.c (3) Identification of Roof Leader, Cellar, Yard and Area Drains, Abandoned Building Sewers, Faulty Connections and Illegal Connections - Most of these inflow sources are located on private properties. The property owners should be notified before the tests to identify the aforementioned inflow sources. To identify the above mentioned inflow sources, dyed water is poured into the corresponding fixtures and their presence is checked in the closest downstream manhole in the sanitary sewer system. The date of the test, the address where the inflow sources are identified and the type of inflow sources should all be recorded.

4.3.3.c (4) Identification of Structurally Damaged Manholes - The dyed water test can also be used to identify the structurally damaged manholes which impose potential infiltration/inflow problems. This is accomplished by flooding the area close to the suspected manholes with dyed water and observing the presence of the dyed water at the manhole walls.

4.3.3.c (5) Outflow Dye Test - Besides being a technique for identifying infiltration/inflow sources, the dyed water testing method can also be utilized to determine the location and quantity of water escaping from a sewer system through bypasses, overflows and cross-connections.

To accomplish this, the downstream manhole of the sewer section is first plugged. The sewer section is then surcharged with dyed water to the desired level. Upon attaining the desired condition, all suspected areas, such as creeks, ditches, storm sewers, catch basins and nearby sewer lines, are visually inspected for the appearance of the dyed water. Record the location, time and duration of test, water level, amount of water used and location of all cross-connections or outflow sources detected and estimate the loss of flow from each of these outflow sources.

4.3.4 Water Flooding Test

The water flooding test is similar to the dyed water testing method except that no dye is used. Because of the lack of a visible indicator in the water flooding test, the task of identifying the infiltration/inflow sources becomes more tedious. Accurate flow measurements are essential to the successful application of this technique. With proper flow monitoring, all the infiltration/inflow sources which can be identified by the dyed water testing method can also be identified by the water flooding test.

In addition, the following two types of water flooding tests can also be performed without the need of the dyed water:

- Sprinkler test
- Exfiltration test

4.3.4.a Sprinkler Test

The sprinkler test is used to determine the quantity of infiltration being experienced in sewer lines under unpaved areas, particularly service connections, during wet weather conditions.

The rainfall is simulated by sprinkling the areas above the sewer lines to be tested with water, using the irrigation sprinkling pipe with spray nozzles or yard sprinkling hoses. The rate of application of water and total water distributed are monitored by installing rainfall gauges in the immediate area of the test. Flows are periodically measured at the manholes both upstream and downstream of the test section. Comparison of these flow readings would determine the quantity of infiltration (if any) and the time required for the infiltration to reach the sewer section.

The data to be recorded may include type, size, depth, number of taps on and location of sewer lines tested as well as topography, soil type, time and duration of test, rainfall gauge readings and flow readings versus time.

4.3.4.b Exfiltration Test

The exfiltration test is used to check the sewer lines and manholes for possible leakages. Sewer sections and manholes which do not show significant exfiltration rates during this test usually would not display high infiltration rates during wet weather conditions. The results from exfiltration tests can also be compared with the infiltration rates determined by the sprinkler tests in a given area. If a definite relationship can be established, the exfiltration test can be used to replace the more costly sprinkler test in that area.

The procedures involved in the exfiltration test are as follows:

(1) Isolate the manholes and sewer lines to be tested by plugging incoming and outgoing lines.

(2) Fill the manholes and sewer lines with water and allow the water surface to stabilize.

(3) Measure the rate of recession of water in the manhole and amount of water required to refill the sewer section.

(4) Record the location, length, depth, type of pipe and manhole construction, and number of taps in the test section. Also record the time and duration of the test, head established, rate of water loss and amount of water required to refill the test sections.

(5) Calculate the exfiltration rate from the test section.

4.4 PREPARATORY CLEANING

4.4.1 General

After the physical survey and the rainfall simulation, the general conditions of the sewer system can be determined. Sewer sections which present obvious potential for excess infiltration/inflow are selected for internal inspection to pinpoint the causes, sources and magnitudes of infiltration/inflow before being recommended for rehabilitation. To facilitate the internal inspection, the sewers should be properly cleaned.

The preparatory cleaning should remove all the sludge, mud, sand, gravel, rocks, bricks, grease and roots from the sewer pipes, manholes and pumping station wet wells to be inspected. The cleaning is normally more thorough than that done for routine maintenance. The pipe walls should be clean enough for the camera used in the inspection to discern structural defects, misalignment and infiltration/inflow sources. A full-diameter tool or cleaning device is often needed to assure adequate cleanliness and clearance.

The cleaning is usually far more time-consuming than the actual internal inspection. For this reason, it is not advisable to have a television camera on site at all times while the cleaning crews are working. However, for lines which clog easily, the inspection should be done as soon as possible after the cleaning is finished to avoid the necessity for recleaning at a later time.

4.4.2 Equipment

A complete sewer cleaning job involves the following four tasks:

(a) Dislodging the materials,

(b) Transporting the materials to a point of access,

(c) Removing the materials from the sewer system,

(d) Disposing of the materials.

The equipment required to accomplish these tasks can be divided into three general categories:

- Cleaning equipment,
- Debris removal devices,
- Debris transporting vehicle.

4.4.2.a Cleaning Equipment

The cleaning equipment is used to dislodge the materials in the pipeline and to transport the materials to the point of access. Most cleaning equipment cannot be used to remove the materials from the sewer system but some may also be used to accomplish this task. There are four basic types of sewer cleaning equipment:

- Rodding machines,
- Bucket machines,
- High-velocity water machines,
- Hydraulically propelled devices.

These types of equipment differ in their capacities to handle the materials in the sewers, applicable pipe size ranges, manhole accessibility requirements and methods of operation. (Table 4-3).

The rodding machines are most effective in dislodging roots and blockages in sewer lines. The bucket machines are most suitable for heavy cleaning which involves the removal of sand, gravel, rocks, bricks and roots. The high-velocity water machines and the hydraulically propelled devices can both be used for light cleaning to remove the sludge, mud, sand and gravel in the sewers.

4.4.2.b Debris Removal Devices

The debris removal devices are used to remove the materials from the sewers after the materials are dislodged and transported to the points of access (manholes) by the cleaning equipment. The commonly used debris removal devices are:

- Vacuum Machines
- Trash Pumps

The bucket machines used for the cleaning can also be used to remove the debris from the sewers.

4.4.2.c Debris Transporting Vehicle

The debris transporting vehicles, or dump trailers, are used to transport the debris to a dump site. The vehicles are sometimes equipped with pumps and settling baffles for separating the solids from the water.

4.4.3 Selection of Cleaning Equipment

To select proper types of cleaning equipment for the preparatory cleaning of a sewer system, many factors have to be considered, including:

- Access to manholes,
- Condition of manholes,
- Size of pipe,
- Depth of deposition,
- Type of solid materials to be removed,
- Degree of root intrusion,

TABLE 4-3

CHARACTERISTICS OF SEWER CLEANING EQUIPMENT [9]

Equipment	Applicable Pipe Size	Materials to be Removed	Advantage	Limitation
Rodding Machines	6"-15"	1. Best for dislodging roots and blockages 2. Also for dislodging and transporting sludge, mud and grease, using special tools and flushing water	1. May reach 1,000 ft 2. Easy to stop 3. Can be used for threading sewer	1. Require direct access to downstream manhole 2. Require large quantity of water for flushing 3. Poor in transporting heavy solids 4. Do not remove materials from sewer.
Bucket Machines	8"-36"	1. Best for dislodging, transporting and removing sand, gravel, rocks, bricks and roots 2. Also for dislodging and transporting mud and grease	1. Can remove large amounts of heavy solids and roots 2. Effective in large diameter pipes 3. Can remove materials from sewer system 4. Winch machine can be used with a variety of tools	1. Require complete access to both manholes 2. Require threading of sewer line 3. Time-consuming for light cleaning 4. Heavy tools may damage pipe 5. Cannot be used in structurally damaged pipe, offset joints, curved pipe and pipes with intruding service connections

TABLE 4-3 (Continued)

High-Velocity Water Machines	6"-15" or larger	1. Best for dislodging and transporting sludge, mud, sand and gravel 2. Also for dislodging and transporting rocks and grease in pipes up to 12" diameter 3. May be used with special tools to dislodge roots in pipes up to 12" diameter 4. Good for cleaning manhole walls and bench	1. Manhole access is not critical 2. Can be used for threading sewer line 3. Easy to set up and operate 4. Fast cleaning method 5. Low pipe-damage potential	1. Require access to downstream manhole 2. Water must be available near job 3. Least effective on large heavy debris 4. May damage deteriorated pipe 5. Do not remove materials from sewer
Hydraulically Propelled Devices	6"-36"	1. Best for dislodging and transporting sludge, mud and sand 2. Also for dislodging and transporting gravel, rocks, bricks and grease	1. No equipment access limitations 2. Minimum equipment requirements 3. Ease of operation	1. Require large quantity of water at site 2. May cause basement flooding 3. Not applicable to blockage resulting in surcharge conditions 4. Do not remove materials from sewer

- Depth of sewer,
- Amount of flow,
- Structural integrity of pipe,
- Availability of hydrant water,
- Degree of cleanliness required.

A review of the general characteristics of the sewer cleaning equipment (Table 4-3) and the results of the physical survey will indicate the cleaning equipment which should be used for each section of sewer recommended for cleaning. Firms experienced in sewer cleaning should be consulted for detailed information on operational procedures and other specific features.

4.5 INTERNAL INSPECTION

4.5.1 General

Following the preparatory cleaning, the sewer sections are internally inspected to determine the location, condition and estimated flow rate for each source of infiltration/inflow defined in the sewer sections. During the inspection, all the infiltration/inflow sources, structural defects, service connections, abnormal conditions and other pertinent observations are recorded. The results from the inspection provide a factual base for the cost-effectiveness analysis to determine the sewer lines which can be cost-effectively rehabilitated and for the selection of the most suitable methods for rehabilitation. The information documented during the inspection can also be used to locate the pipelines and problem sections in the pipes during actual rehabilitation.

Internal inspection is normally conducted during periods of maximum groundwater levels. However, for sewer lines which are above the groundwater levels throughout the entire year, the inspection can be performed any time. During the inspection, all storm sewer sections, stream sections, ditch sections, and ponding areas which are found to contribute infiltration/inflow to the sanitary sewer section should be flooded. The purpose is to duplicate the worst possible weather and groundwater conditions in the sewer sections so all the infiltration/inflow sources will show up during the inspection.

4.5.2 Inspection Techniques

Sewer inspection can be accomplished by any one of the following four techniques:

- Television inspection,
- Photographic inspection,
- Physical inspection, and
- Air test.

The television inspection technique is most commonly used; however, the photographic, physical inspection and air test techniques can also be used under special conditions. The method used for internal inspection should be the best and most cost-effective method of obtaining the necessary information.

4.5.2.a Television Inspection

The television inspection technique utilizes a closed-circuit television camera to observe the conditions in the sewer lines. The results are shown in the television monitor. Documentation can be made with videotape or photographs of the monitor. The technique can be applied to sewers with sizes ranging from 8 to 36 inches and with lengths up to 1,000 feet (Figure 4-1).

4.5.2.a (1) Equipment - The cameras used for TV inspection are specially designed to fit the sewer pipe conditions. The camera is mounted in a casing and is pulled through the sewer with cables. A light source is provided along with the camera for illumination purposes. A TV monitor is used to show the actual conditions in the sewer as the camera is pulled along.

4.5.2.a (2) Procedure - During the inspection, the cameras are stopped at the points where one or more of the following conditions are observed:

- Infiltration/inflow sources;
- Service connections;
- Structural defects, including broken pipe, collapsed pipe, cracks, deterioration, punctures, etc.;
- Abnormal joint conditions, such as horizontal and vertical misalignments, open joints, joints not fully seated, etc; and
- Unusual conditions, such as root intrusion, protruding pipes, in-line pipe size changes, mineral deposits, grease, obstructions, etc.

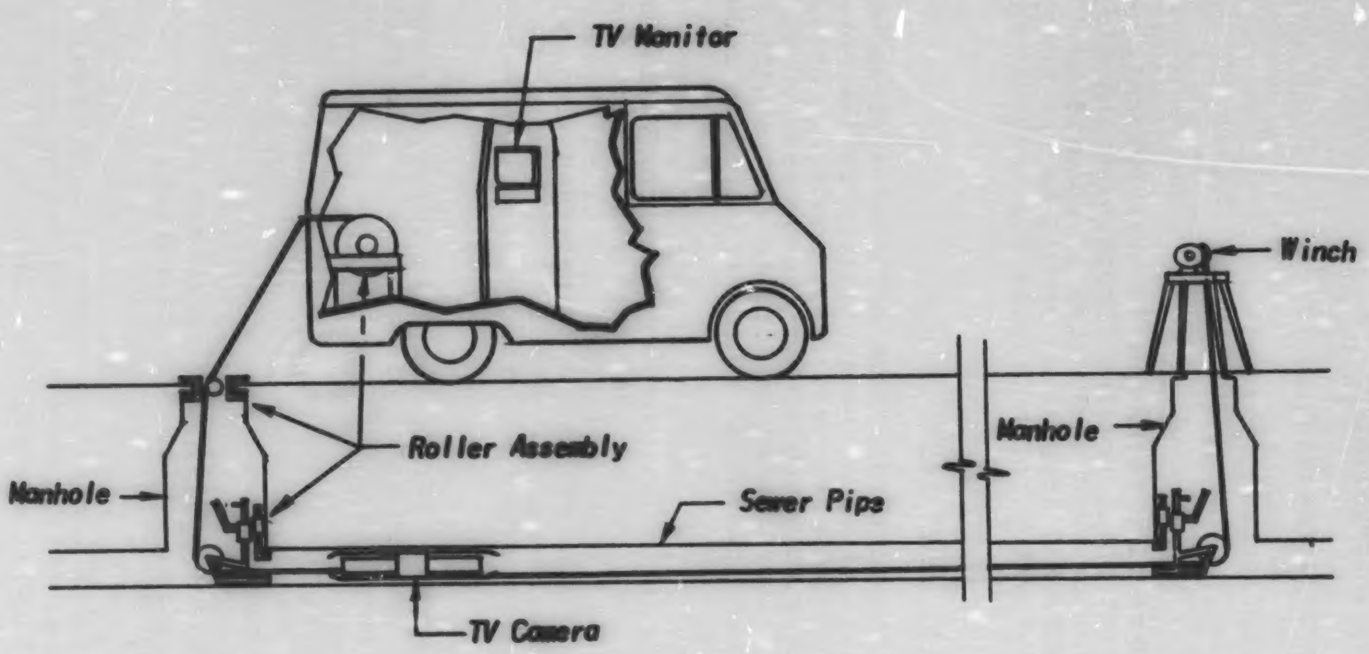
TV Monitor
Winch
Manhole
Roller Assembly
Manhole
Sewer Pipe
TV Camera

Figure 4-1. Typical Arrangement for Television Inspection of Sewer Lines

All such conditions should be recorded. Photographs of all questionable conditions should be taken for subsequent review. The photographs are usually taken from the TV monitor with Polaroid or 35 MM films. All infiltration/inflow sources should be quantified while observing through the TV monitor (see Section 4.5.2.a (3) for detail). If necessary, the infiltration/inflow sources may also be recorded with videotape for flow estimation in the laboratory and for later review. Before taking the photographs or videotape, the TV camera should be properly positioned so that the optimum view of the defects, etc., can be obtained. If necessary, the same problem object can also be viewed from the opposite direction by pulling the TV camera from the other manhole in the sewer section. For reference purposes, photographs and videotapes of typical sewer sections and joints in lines being inspected should also be taken.

At the connecting points between the service connections and the sewer being inspected, the TV camera should be stopped to check for any flows coming out of the service connections. Whenever a flow is observed, its source should be checked out immediately. The building to which the service connection is connected should be checked first for any wastewater discharge during the inspection. If no flows are being discharged from the building, then it can be assumed that the observed flow is infiltration or inflow. If the estimated flow from the service connection is greater than the total wastewater discharge from the fixtures in the building, then the infiltration/inflow can be determined by calculating the difference of these two flows.

The locations of all the conditions recorded should also be identified by recording the distance from each defect or point of interest to an established point in each sewer section. The distance is usually measured from the center of the starting manhole to the plane of focus of the camera.

Table 4-4 shows a typical television inspection log sheet. In addition to the columns for recording the footage, observations and infiltration/inflow rates, the sheet also includes columns for recording the recommended corrective action and the photograph number. The recommended corrective action for each pipe defect or infiltration/inflow source is based on the conditions of the defect or the type of infiltration/inflow source. This information is essential for conducting the cost-effectiveness analysis and for planning the sewer rehabilitation program. For the convenience of cross-reference, the photographs should be numbered and the photograph number for each item should be recorded on the log sheet.

TABLE 4-4

TYPICAL TELEVISION INSPECTION LOG SHEET

AREA____________ SHEET NO.__________

PROJECT:________________________ PROJECT NO:________ DATE:____________

CLIENT:__________________________________ INSPECTOR:__________

SECTION ON:____

FROM MANHOLE #____________________ TO MANHOLE #____________________

PIPE SIZE_____IN., PIPE TYPE______ PIPE LENGTH____FT TYPE OF JOINTS_________

REF. NO.	FOOTAGE	OBSERVATIONS	INFILTRATION/ INFLOW gpm	RECOMMENDED CORRECTION ACTION	PHOTO NO.
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
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SPECIAL NOTES______________________________

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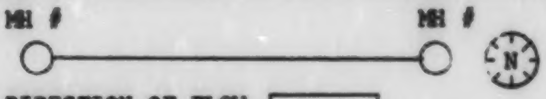


DIRECTION OF FLOW ▭

DIRECTION OF MEASUREMENT ▭

4.5.2.a (3) Estimation of Infiltration/Inflow Rates - Estimating the flow rates of the infiltration/inflow sources through a television camera is a difficult task. The accuracy of the estimate depends largely on the experience of the operator in front of the TV monitor or the person reviewing the videotapes. The experience is usually gained by observing the infiltration/inflow conditions simulated in the laboratory and comparing the estimated flows with the measured flow rates.

A simple laboratory simulation technique for testing the estimation of flows from the infiltration/inflow sources in the sewer pipes is illustrated in Figure 4-2. A section of sewer pipe of the same size and type as the sewer to be examined is used for the test. On this section of pipe, a defect is created to simulate a certain condition in the actual sewer line. The pipe is installed in an inclined position in a water container which has two holes in the opposite walls. The adjustable rubber ring is tightened around the pipe to assure watertightness. A television camera is pulled into the pipe section and focused to give a clear view of the defect on the pipe wall. Water is added to the water container to a desired level. The person being trained may then proceed to turn on the TV monitor and watch the shape and speed of the water leaking through the pipe defect very carefully from the screen. Record the flow with videotape if desired. Gather the water flowing out of the pipe with a bucket and record the starting and ending time with a stop watch. Measure the volume of water gathered and calculate the flow rate. Correlate the measured flow rate with the shape and flow speed shown in the TV monitor. Repeat the process for different water heads, type and size of pipe defects, pipe size and pipe material to cover as many field pipe conditions as possible. The videotape recorded during the test can be used for repeated training of the field TV inspectors.

However, even with the simulation technique, it is often not possible to accurately determine the infiltration/inflow rates in the field. Whenever possible, the infiltration/inflow rate in a sewer section should be measured by plugging and weiring (or by other flow measurement techniques) during the low flow hours. After the normal wastewater flows are deducted, the measured flow rate is compared with the total estimated infiltration/ inflow rate. If the two are not equal, a correction should be made to adjust the estimated flow rate. This can be done by dividing the measured total flow rate by the estimated total flow rate. The resulting factor is used to multiply the estimated flow rate from each individual source to derive the corrected flow rate.

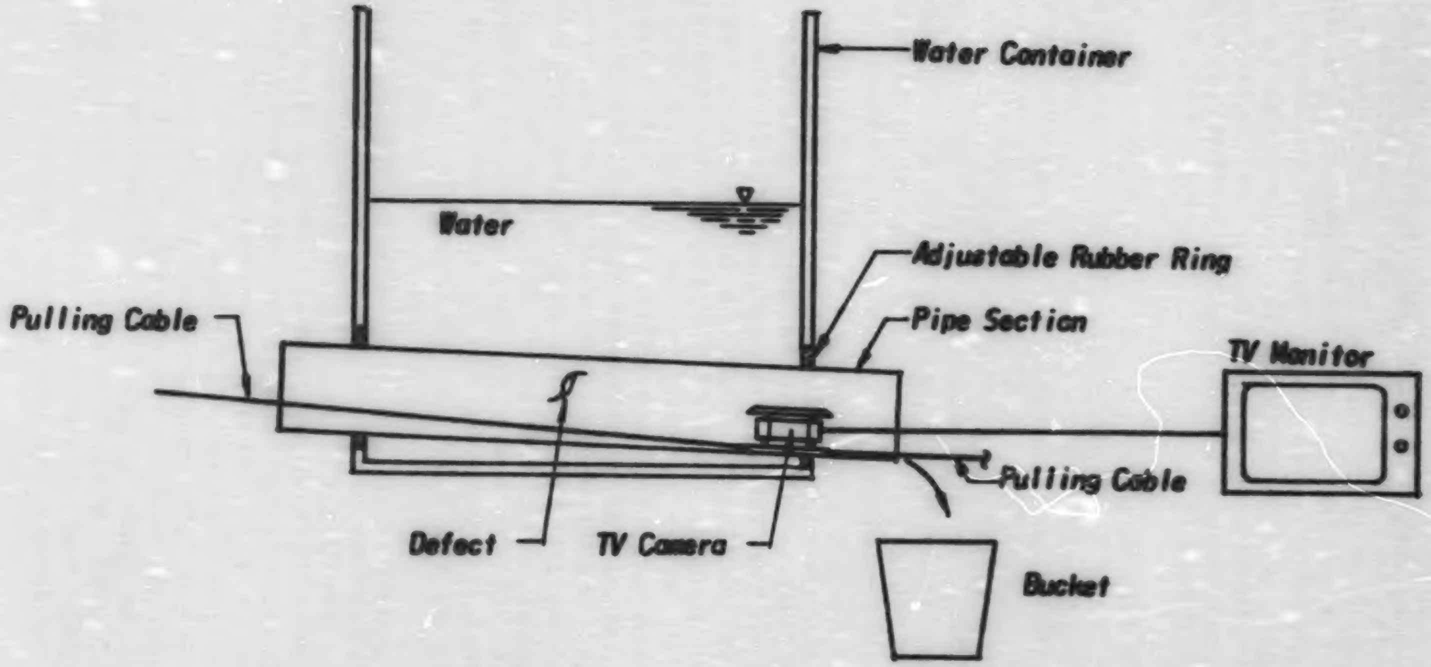

Water Container
Water
Adjustable Rubber Ring
Pipe Section
Pulling Cable
TV Monitor
Pulling Cable
Defect
TV Camera
Bucket

Figure 4-2. Laboratory Test for Estimating Infiltration/Inflow Rates

4.5.3 Photographic Inspection

The photographic inspection technique uses a camera to take a series of color photographs along the inside of the sewer lines. The technique can be applied to sewers with sizes ranging from 8 to 36 inches.

The technique is best for analyzing the structural conditions of the sewers. The photographs can also be used to determine the joint conditions and root intrusion problems in the sewers.

In applying this technique, a camera is pulled through the sewer line being inspected. Pictures are taken at equidistant intervals or at some predetermined problem sections. The distances at which the pictures are taken are measured from a reference point, usually the center of the starting manhole.

4.5.4 Physical Inspection

Two physical inspection techniques can be used to inspect the sewer:

- Lamping
- Entering (large sewers only)

The lamping inspection technique has been discussed in the section on Physical Survey (Section 4.2.4). The entering inspection technique is a direct method for sewer inspection. However, this technique is usually limited to new construction, large storm sewers and large sewers not in service. In applying this technique, the safety of the person entering the line should always be carefully guarded. Before entering the line, the sewer section should be thoroughly ventilated to remove all the harmful gases. Forced ventilation should be provided throughout the inspection period. The person entering the line should be provided with redundant lights as well as all the personal safety equipment required for manhole and sewer inspection (See Section 3.2.6.d.)

4.5.5 Air Test

Specific circumstances may warrant the use of air testing of sewer joints, in conjunction with television inspection, to accomplish internal inspection. This technique may be employed on projects which have missed the high groundwater period and economics would justify an air testing program to avoid a costly delay of the project.

The procedure for air testing is described in Chapter 5, Section 5.3.2.c(1).

4.6 SURVEY REPORT

4.6.1 General

After finishing all the investigative work, a survey report has to be prepared. A complete survey report usually contains the following items:

(a) A description of all the tasks performed, covering:

- The purpose of conducting each task,
- The methods and equipment used,
- The location of the study area and/or the sections of sewer lines investigated;

(b) A summary of all the results gathered during the investigation;

(c) A cost-effectiveness analysis to determine the portion of sewer sections which can be cost-effectively rehabilitated and the infiltration/inflow which is expected to remain in the sewer system after rehabilitation;

(d) A proposed sewer system rehabilitation program and its related costs;

(e) A documentation of all the field data gathered during the investigation.

For clarity, the results, conclusions and recommendations are usually summarized in tabulated forms and illustrated on maps.

4.6.2 Data Analysis

The initial step in the preparation of a survey report is a summarization, in tabulated forms, of the results of all the tasks performed in the evaluation survey. The following table headings are suggested for each respective task:

(a) Physical Survey

(1) Aboveground inspection: Location; observation

(2) Flow monitoring: Location; key manhole number; sewer lines (size and length); method of measurement; test condition (dry weather and wet weather); measured infiltration (gpd and gpd/in-mile of sewer); suggestion for further study.

(3) Groundwater test: Manhole number; date; measurement device; groundwater level.

(4) Manhole inspection: Location; manhole number; type of construction; structural condition; infiltration/inflow sources; estimate flow rate; remarks; reference page of field report.

(5) Sewer inspection: Location; sewer section number (or, manhole numbers); type; length; size; deposition (type and depth); visible infiltration/inflow sources; structural condition; special problems; recommended cleaning method; recommendation for internal inspection; reference page of field report.

(b) Rainfall Simulation

(1) Smoke testing: Location; test conditions; observation; conclusions; recommendations.

(2) Dyed water testing: Location; test conditions; observed infiltration/inflow sources; estimated flow rate; conclusions; recommendations.

(3) Water flooding test: Location; test conditions; observed infiltration/inflow sources; estimated flow rate; conclusions; recommendations.

(c) Preparatory Cleaning

Location; sewer section number (or, manhole numbers); pipe (size and length); deposition (type and depth); cleaning method used.

(d) Internal Inspection

Location; sewer section number (or, manhole numbers); observed leakage (type, location and flow rates); recommended corrective action; reference page of field report.

A detailed sewer map is usually included in the report. The map should show all the manholes, pumping stations, bypasses, overflows, and sewer lines in the sewer system under study. For reference purposes, the manholes should be properly numbered. The size, material and flow direction of each sewer section should be clearly indicated. The important information related to the evaluation survey can also be shown in the sewer map. This information may include:

- Special problems observed during aboveground inspection;
- Key manholes for flow monitoring and flow-monitored sewer lines;
- Groundwater monitoring station;
- Manholes and sewer lines inspected during physical survey;
- Sewer sections investigated by smoke testing, dyed water testing or water flood testing;
- Sewer sections cleaned and internally inspected;
- Sewer sections justified for internal inspection but nonaccessible.

4.6.3 Cost-Effectiveness Analysis

4.6.3.a Introduction

After all the results have been analyzed and summarized, a cost-effectiveness analysis should be conducted to determine which portion of the infiltration/inflow conditions in the sewer system can be cost-effectively corrected. The methodology for conducting the cost-effectiveness analysis is basically similar to that presented in Section 3.4.3.c for the Infiltration/Inflow Analysis. However, in the Sewer System Evaluation Survey Phase, the types of infiltration/inflow sources, the flow rate from each source, the best method for correcting each source and the costs for the corrections are all better defined than they were in the Infiltration/Inflow Analysis Phase. Therefore, somewhat different procedures can be used.

4.6.3.b Flow Adjustment

Before the cost-effectiveness analysis can be conducted, the estimated flow from each infiltration/inflow source should be adjusted. The following are the recommended procedures:

4.6.3.b (1) Flow Adjustment for Peak Infiltration -

(a) Determine the sum of estimated flows from all infiltration sources.

(b) Compare the total flow with the total peak infiltration determined in the Infiltration/ Inflow Analysis. If the former is greater than the latter, no flow adjustment will be needed. If the reverse is true, calculate the ratio of the latter over the former and multiply the estimated flow from each source by this ratio to derive the adjusted flow, which is then used in the cost-effectiveness analysis.

4.6.3.b (2) Flow Adjustment for Peak Inflow - The estimated peak inflow values should be adjusted for the desired design period or design condition. The design rainfall frequency normally used for designing storm sewers should be used for such adjustment. The ratio of the design and observed rainfall intensities is used to adjust the peak inflow.

4.6.3.c Cost Estimation

Two types of costs need to be developed:

- Costs for the correction of infiltration/inflow conditions,
- Costs for transportation and treatment of wastewater (including infiltration/inflow).

The cost for the correction of infiltration/inflow conditions should be developed for each individual infiltration/inflow source. The cost for both the Evaluation Survey and the Rehabilitation should be included. (The Cost for the Evaluation Survey has been expended; however, it should be included in the cost-effectiveness analysis in the Evaluation Survey Report because (1) it was included in the cost-effectiveness analysis in the Infiltration/Inflow Analysis Report and (2) the cost-effectiveness analysis in the Evaluation Survey is intended to be a refinement of that in the Infiltration/ Inflow Analysis.) The estimated cost of the Evaluation Survey for each source should be based on the total money actually expended for Evaluation Survey in the entire sewer system. Estimated costs for rehabilitation should be based on the actual physical conditions discovered.

The costs for transportation and treatment of wastewater can be developed following essentially the same procedures as those presented in Section 3.4.2.d. Costs should be developed for at least four typical flow conditions so that a cost curve can be drawn to indicate the general cost pattern.

4.6.3.d Analysis Procedures

The analysis procedures are as follows:

(1) Determine the total correction cost for each infiltration/inflow source and calculate the cost required for eliminating each unit of flow (the unit cost).

(2) Arrange the infiltration/inflow sources in order, putting the sources with lower unit costs ahead of those with higher unit costs.

(3) With the sources arranged in order, break them into several groups and determine the total correction cost as well as total infiltration/inflow to be reduced for each group. Add to the total correction cost the engineering services costs; legal, fiscal and administrative costs; contingency costs; interest during construction; etc., to derive the total cost required to eliminate the infiltration/inflow from all sources within each group.

(4) Arrange the groups in order, putting the groups with lower total cost ahead of those with higher total cost, and, calculate the accumulative total cost and accumulative total infiltration/inflow to be reduced.

(5) Plot the accumulative total cost against the accumulative total infiltration/inflow to be reduced and draw a curve passing all data points. (Cost Curve for Rehabilitation shown in Figure 4-3).

(6) On the same graph, plot a curve to show the relationship between the costs for transportation and treatment and the total infiltration/inflow to be reduced (Cost Curve for Transportation and Treatment shown in Figure 4-3).

(7) Derive a Composite Cost Curve (Figure 4-3) by adding the costs on the two derived curves.

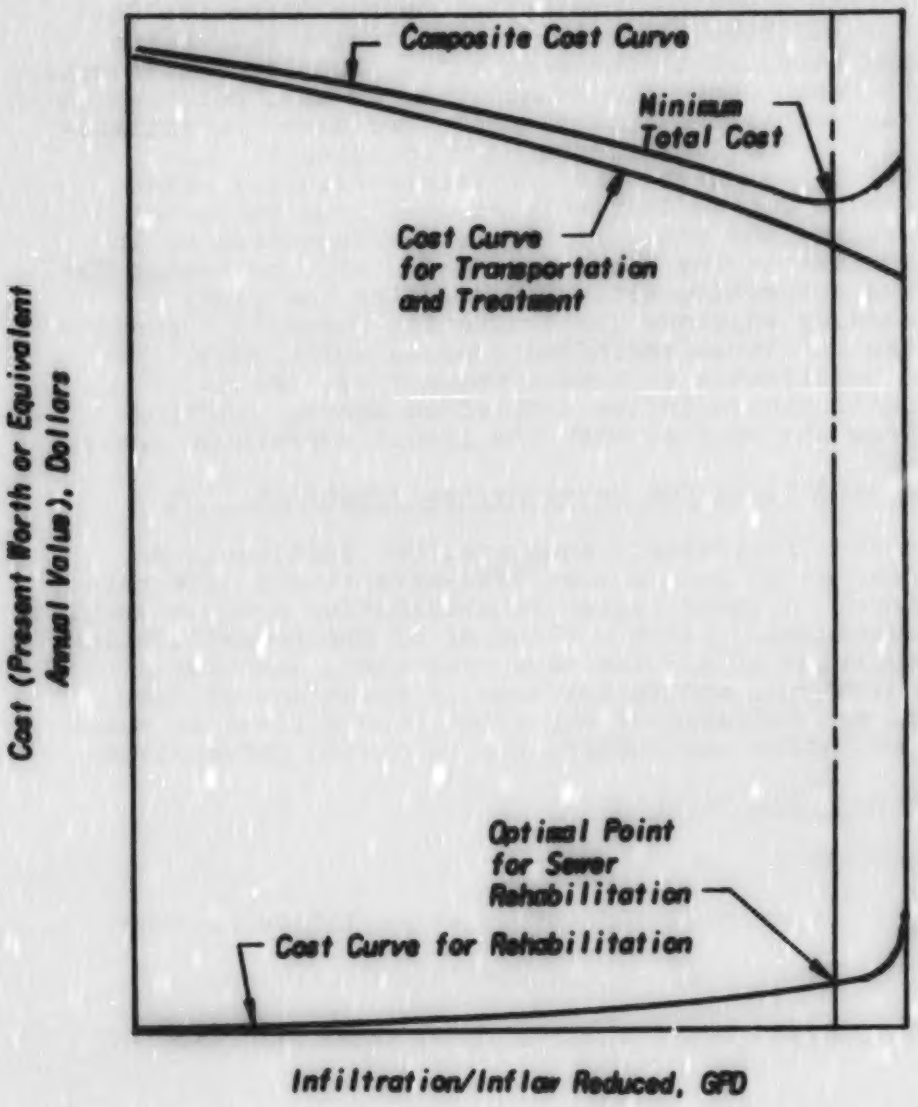


Figure 4-3. Cost Curves for Cost-Effectiveness Analysis in Evaluation Survey

(8) Locate a minimum cost point on the Composite Cost Curve. Draw a straight line passing this point and parallel to the cost axis. The line intercepts the Cost Curve for Rehabilitation at a point which represents the optimal point for sewer rehabilitation. The flow figure corresponding to this point represents the infiltration/inflow which can be cost-effectively removed from the sewer system, and the cost figure corresponding to it represents the total cost which will be needed for the corrective actions (including the money already expended for Evaluation Survey). Determine the infiltration/inflow sources which should be rehabilitated to remove the optimal amount of infiltration/inflow determined above, starting from the sources with the lowest correction costs.

4.6.4 Recommendations for Sewer System Rehabilitation

After the cost-effectiveness analysis, the infiltration/inflow sources which can be most cost-effectively eliminated are determined. A sewer system rehabilitation program should then be recommended. For the planning of the rehabilitation work, a tabulation of all the sewer sections, manholes, service connections, and inflow sources which can be cost-effectively rehabilitated or corrected should first be made. A typical tabulation may include the following information:

(a) Sewer Line Rehabilitation

(1) Method of rehabilitation;

(2) Description of infiltration/inflow sources;

(3) Sewer line or manhole identification;

(4) Sewer length, size, type, depth and type of cover;

(5) Location of infiltration/inflow sources in pipe;

(6) Section of pipe to be rehabilitated.

(b) Manhole Rehabilitation

(1) Method of rehabilitation;

(2) Description of infiltration/inflow sources;

(3) Manhole identification;

(4) Type and depth of manhole.

(c) Service Connection

(1) Method of rehabilitation;

(2) Description of infiltration/inflow sources;

(3) Address of service connection;

(4) Sewer line to which the service connection is connected;

(5) Length of service line;

(6) Type of cover.

(d) Inflow Sources

(1) Method of correction;

(2) Description of inflow source;

(3) Location of inflow source.

Whenever possible, the time schedule for the proposed rehabilitation work and related costs should also be included in the recommendation. For the benefit of a continued operation and maintenance program, it is also advisable to tabulate all the problems in the sewer system observed during the evaluation survey.

CHAPTER 5

SEWER SYSTEM REHABILITATION

5.1 INTRODUCTION

The sewer system rehabilitation involves all the work that is necessary to correct the infiltration/inflow conditions which were found to be cost-effective to correct in the Sewer System Evaluation Survey.

The infiltration and inflow sources which are commonly found in sewer systems are shown in Table 5-1. In the same table, the possible correction methods for each source are also shown.

The correction methods for inflow sources are relatively simple and will not be considered in further detail. The techniques which are most frequently used for correcting infiltration sources include [9]:

(a) Excavation/Replacement

(b) Chemical Grouting

    (1) Acrylamide gel
    (2) Polyurethane foam

(c) Pipe Lining (Slip-lining)

    (1) Polyethylene pipe
    (2) Fiberglass-reinforced polyester mortar pipe

(d) Pipe Lining

    (1) Cement mortar
    (2) Epoxy mortar

The advantages, limitations, applications and procedures of these techniques are discussed in the following sections.

Engineers should be aware of any new products which may be made available in the future. The use of new products is encouraged if they are proved to be effective.

For applications, only the most effective technique or material should be used. When several techniques or materials are equally effective, the one with the minimum overall cost should be chosen.

TABLE 5-1

INFILTRATION/INFLOW SOURCES AND CORRECTION METHODS

Sources	Possible Correction Methods
Infiltration Sources	
Collapsed pipe	Replacement; slip-lining
Broken or crushed pipe	Replacement; slip-lining
Cracked pipe	Slip-lining; lining with cement mortar or epoxy mortar; replacement
Deteriorated pipe joints	Chemical grouting
Leaking off-set joints	Slip-lining; chemical grouting; replacement
Open joints	Slip-lining; chemical grouting; replacement
Deteriorated mortar joints in brick pipes	Brick mortar replacement
Leaking house service connections	Chemical grouting; slip-lining; replacement
Faulty taps between sewers and manholes	Excavation and repair
Faulty taps between service connections and main sewers	Excavation and repair
Collapsed manhole and wet wells	Replacement
Deteriorated manhole walls, bases and troughs	Lining with cement mortar or epoxy mortar; chemical grouting; cement grouting
Deteriorated mortar joints in brick manholes	Brick mortar replacement
Deteriorated wet wells and pumping station structures	Lining with cement or epoxy mortar
Other sources such as deteriorated regulators, tide gates, etc.	Repair according to situation

TABLE 5-1 (Continued)

Sources	Possible Correction Methods
Inflow Sources	
Low lying manholes	Manhole raising
Perforated manhole covers	Replace with water tight covers
Cross connections	Plugging
Roof leader drains	Disconnection
Foundation drains	Disconnection
Cellar drains	Disconnection
Yard drains	Plugging
Area drains	Plugging
Cooling water discharge	Disconnection
Drains from springs and swampy areas	Plugging

5.2 EXCAVATION/REPLACEMENT

This technique involves the removal of the existing pipes or manholes from the ground and replacing them with new ones. If suitable material and construction methods are utilized, the technique may produce the most effective rehabilitation results. The cost of this technique, however, is normally much higher than other rehabilitation techniques and the time requirement is usually much longer.

The technique is normally considered for application under one or more of the following conditions [9]:

- In locations where pipes or manholes have lost their structural integrity, such as pipes or manholes which are collapsed, crushed, broken, or badly deteriorated and cracked;
- In cases where pipe size enlargement, change in grade and/or line realignment are needed in addition to pipe deficiency corrections;
- In cases where the causes of damages to the existing pipes or manholes (such as corrosion, soil movement, increasing traffic load, etc.) have been identified and it is desirable to prevent the reoccurrence of these damages by replacing the existing structures with new ones having better quality and greater strength.

Just as for new sewer construction, this rehabilitation technique may require the removal of pavement, disruption of traffic, dewatering, well-pointing, shoring, interference with utilities and structures, and repavement. In addition, during the construction period, the sewage flows in the sewer sections should also be bypassed. All the costs involved in these tasks should be considered when comparing this technique with other rehabilitation techniques.

5.3 CHEMICAL GROUTING

5.3.1 Introduction

Chemical grouting is most commonly used to seal leaking joints in structurally sound sewer pipes. With special techniques and tools, the method can also be used to seal leaks in house connections, manhole external drops, manholes, wet wells and pumping station structures.

The information described hereinafter was supplied by American Cyanamid Company and 3M Company. For specific use of these products, the reader should consult with the manufacturers.

Two chemical grouts have been used extensively: acrylamide gel and polyurethane foam. Basically, grouting with the acrylamide gel stops the leaks by internally injecting the grout to the soils surrounding the leaks to decrease their permeability. Grouting with the polyurethane foam, on the other hand, seals the leaks by injecting the grout into the cracks and letting it solidify to form a barrier.

The acrylamide gel was developed in the early 1950's by American Cyanamid Company and was initially used for soil stabilization. It was not used for sewer rehabilitation until 1960. The polyurethane foam was developed in the late 1960's and early 1970's by the 3M Company and has been used for sewer rehabilitation since 1973.

5.3.2 Chemical Grouting With Acrylamide Gel

5.3.2.a Properties of the Acrylamide Gel

The acrylamide gel is commonly known by its trade name, AM-9. The basic chemical used in the acrylamide gel is a mixture of two organic monomers, acrylamide and N,N'-methylene bisacrylamide. The chemical is in the form of a white powder with a specific weight of about 35 pounds per cubic foot. A 10-percent (by weight) aqueous solution of this chemical is usually used for sewer grouting. When the aqueous solution of this chemical is properly catalyzed, gelation occurs through a polymerization-crosslinking reaction.

The catalysts used for the reaction are B-dimethylaminopropionitrile and ammonium persulfate. The former is a caustic solution and is used as an activator for the reaction. The latter is a strong oxidizing agent used as an initiator to trigger the reaction.

In field applications, the monomer powder and the activator are usually dissolved in water in one container and the initiator is mixed with water in a second container. The individual solutions are stable for about two weeks. Gelation occurs when these two solutions are mixed together.

The gel time (or "set time" or "induction time") is primarily affected by the concentrations of the catalysts and the solution temperature. Generally, the higher the catalyst concentrations and the temperature, the shorter the gel time. However, the concentration of the ammonium persulfate should normally be less than 3.0 percent (by weight) since at higher concentrations the mix may be too acidic to gel. Other factors which affect the gel time include monomer concentration, pH, metal ions, salts, particulate matter, hydrogen sulfide and chemical composition of mixing water. By altering the concentrations of the catalysts, the gel times can be controlled from 5 to 500 seconds. A gel time of approximately 20 seconds is commonly chosen in sewer grouting. Longer gel times are used in structural waterproofing which needs deeper penetration at lower flow rates. The effect of catalyst concentration and temperature on gel time has been documented by American Cyanamid Company. (A typical example is shown in Figure 5-1.) Table 5-2 shows the compositions of the grouting mixes suggested by the manufacturer for summer and winter applications at ground temperatures of 60° F and 50° F, respectively.

Before gelation, the grouting mix has a viscosity very close to that of water. This allows it to penetrate into small leaks and cracks in pipe walls and to mingle with outside soil particles. The acrylamide gel formed from the solution is a translucent, rubbery and elastic material. Under moist conditions, the gel is resistant to attack by microorganisms, dilute acids, alkalies, and the ordinary salts and gases normally found in the ground. When the gel is formed in a soil matrix, the permeability of the soil is reduced. The degree of reduction of the permeability depends upon the extent to which the voids are filled with the gel. If they are completely filled, the gel-soil mixture is virtually impermeable.

If allowed to dry, the gel will shrink due to dehydration. In a gel-soil mixture, dehydration may cause shrinkage cracks which would not be rehealed even if the moisture content of the mixture is restored later. However, chemical additives such as ethylene glycol or calcium chloride may be added to the grout to prevent dehydration.

Before gelation, the acrylamide gel is toxic. Inhalation of its vapor, contact with skin and swallowing should all be avoided.

5.3.2.b General Considerations in Applications

The acrylamide gel can be used for sealing pipe joints, but it cannot be used as a structural repair for broken, crushed or badly cracked pipes and appurtenant structures.

In soils containing large interstices, such as coral sand, gravel or rocks, especially in the presence of moving groundwater, the effectiveness of the gel may be reduced. This situation may be remedied by one of the following measures:

(1) Judicious use of shorter gel time

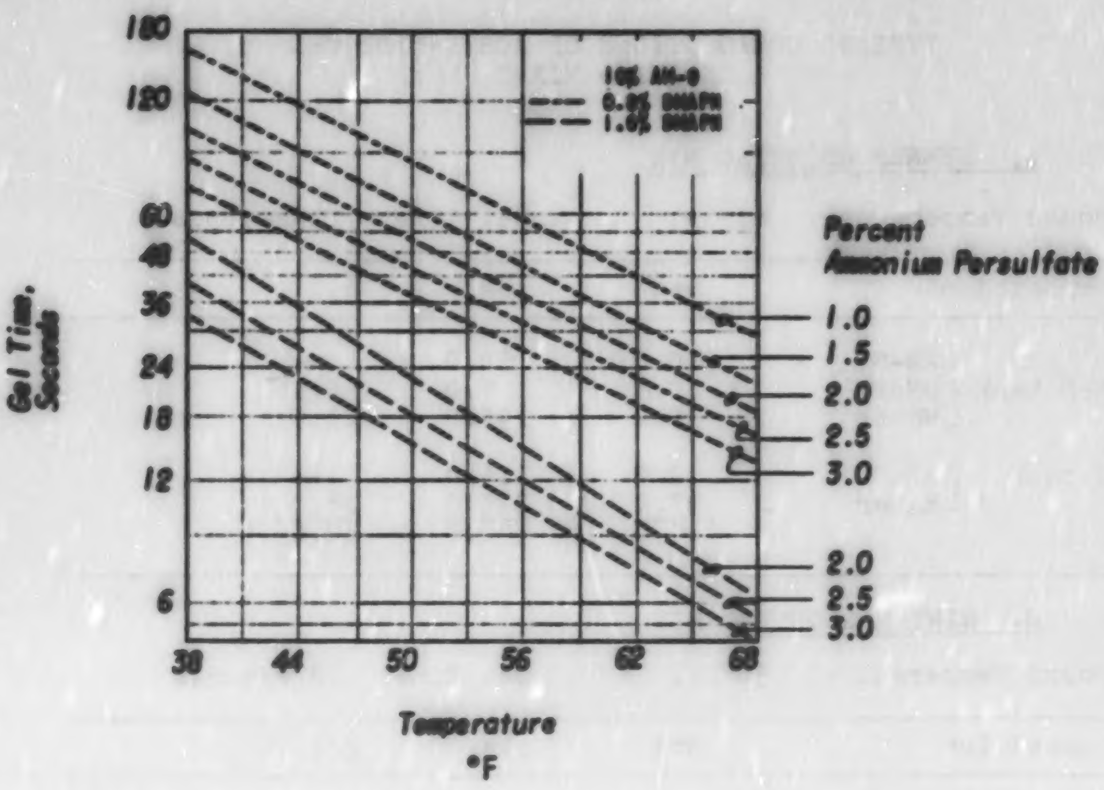


Figure 5-1. Effect of Catalyst Concentration and Temperature on Acrylamide Gel Set Time [10]

TABLE 5-2

TYPICAL COMPOSITIONS OF ACRYLAMIDE GEL GROUTING MIXES [11]

A. SUMMER GROUTING MIX

Ground Temperature: 60° F. Gel Time: 20 seconds

Composition		Wt%	lbs.	gal.
AM-9 tank	AM-9[1]	10.0	50.0	--
	DMAPN[2]	0.8	4.0	0.56
	Water	39.2	196.0	23.5
AP tank	AP[3]	3.0	15.0	--
	Water	47.0	235.0	28.0
		100.0	500.0	60.0

B. WINTER GROUTING MIX

Ground Temperature: 50° F. Gel Time: 18 seconds

Composition		Wt%	lbs.	gal.
AM-9 tank	AM-9[1]	10.0	50.0	--
	DMAPN[2]	1.6	8.0	1.13
	Water	38.4	192.0	23.0
AP tank	AP[3]	2.5	12.5	--
	Water	47.5	237.5	28.0
		100.0	500.0	60.0

---

[1] Mixture of two monomers: acrylamide and N, N'-methylenebisacrylamide

[2] B-dimethylaminopropionitrile

[3] Ammonium persulfate

(2) Intermittent grouting

(3) Using higher gel concentration

Before grouting, the pipes should be cleaned. There should be no obstacles in the pipe to prevent the passage of sealing packer. The sealing packer can only be used at joints where the pipe wall on each side of the joint can provide continuous contact with the packer.

In locations where prolonged dry conditions are expected, dehydration resisting additives should be used.

5.3.2.c Applications

5.3.2.c (1) Sewer Grouting - Grouting of sewer pipe joints is generally accomplished with a sealing packer and a closed circuit television camera. The sealing packer is used to apply the chemical grout to the pipe joint. It is usually made of a hollow metal cylinder which has an inflatable rubber sleeve on each end of a center band. The television camera is used to remotely position the packer on the pipe joint and to inspect the joints before and after the sealing operation. The sealing packer and television camera are pulled by cables through a sewer section from manhole to manhole. In addition, the air testing equipment is sometimes used tc determine the integrity of the joints and to check the effectiveness of the sealing. The practice of finding the leaking pipe joints with the air testing equipment followed by immediate chemical grouting is commonly known as "test and seal".

Figure 5-2 shows a schematic diagram of a sealing packer and a television camera in place during a grouting operation. The procedure is as follows:

(a) Clean the pipe.

(b) With the aid of the television camera, position the sealing packer on the joint to be grouted.

(c) Pump air to the rubber sleeves of the packer until they expand and seal against the pipe wall on both sides of the joint.

(d) If air testing is to be conducted, it is done at this time by applying air pressure to the space created between the two inflated sleeves. The joint is usually considered to be adequate when a pressure equal to or slightly greater than the maximum expected groundwater static head pressure can be maintained for a period of several seconds.

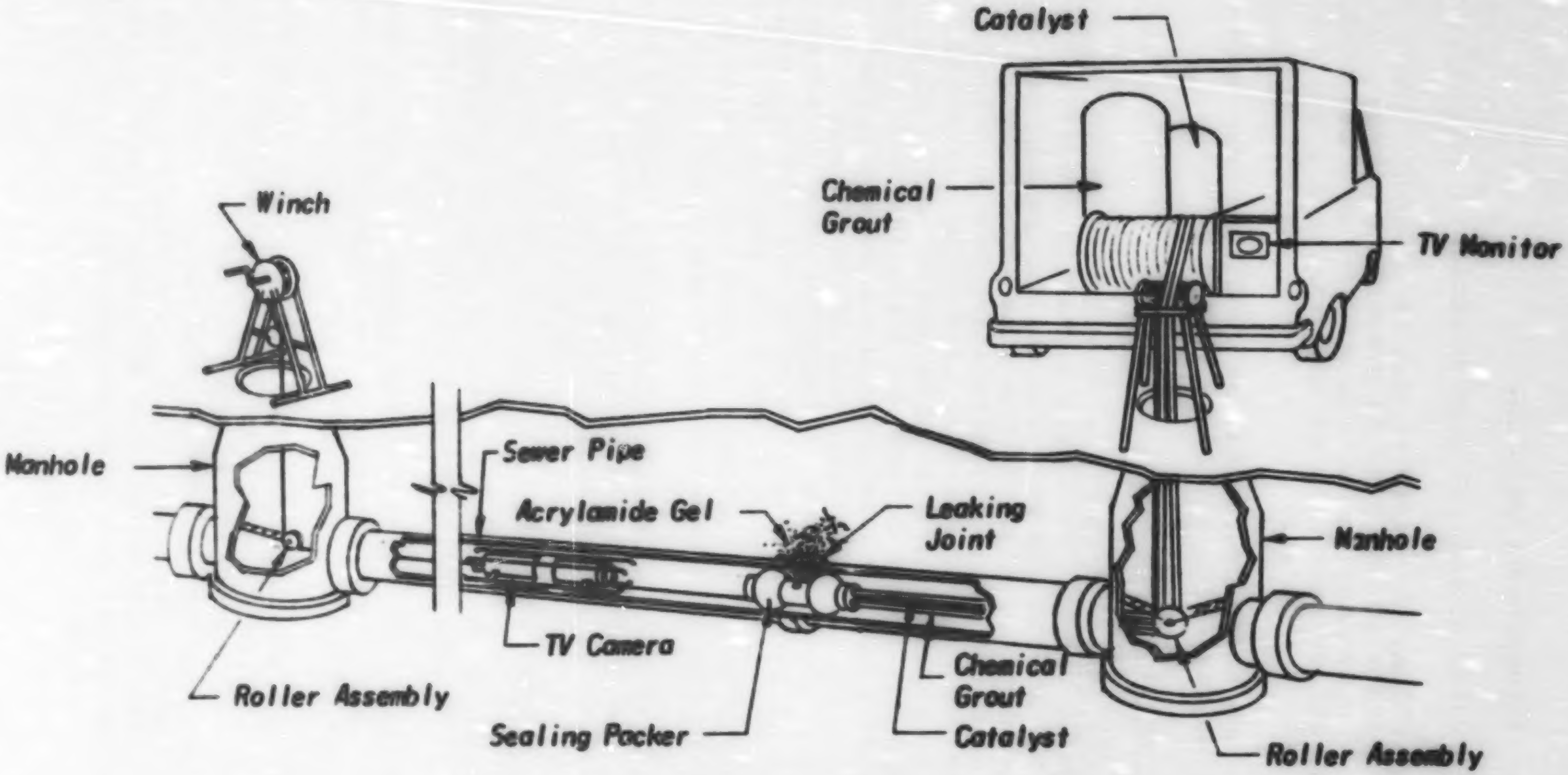

Catalyst
Chemical Grout
TV Monitor
Winch
Manhole
Sewer Pipe
Acrylamide Gel
Leaking Joint
Manhole
TV Camera
Roller Assembly
Sealing Packer
Chemical Grout
Catalyst
Roller Assembly

Figure 5-2. Typical Arrangement for Chemical Grouting with Acrylamide Gel

(e) For the joint which needs sealing, pump the chemical grout into the space created between the two inflated sleeves. In this space, the grout and the initiator solutions are mixed together and squeezed out through the joint leak into the surrounding soil. There, the grout displaces the groundwater and fills the voids between the soil particles.

(f) After proper gelation time, deflate the packer and move it to the next joint. To make certain the sealing is proper, air testing can be conducted. (Before the test, the packer should be deflated and reinflated to break up the gel inside the pipe. The packer can also be used to wipe the pipe before being reinflated.) If the sealing is unsuccessful, more grout can be pumped through the joint until a seal is obtained. The gel formed on the inside of the pipe is very weak and can be washed away easily by the flowing sewage.

5.3.2.c (2) Grouting of House Connections and Manhole External Drops - The acrylamide gel can often be used to seal the leaks in the house connections and manhole external drops. However, because of size and/or access limitations, the sealing packer-television camera technique is normally not applicable. The frequently used technique for the house connection is to pump the grout to fill the entire length of the house connection until the grout exfiltrates through the various leaks. This technique is also applicable to seal manhole external drops. Reaming of the house connection line to remove excess grout may be necessary after the gel time.

5.3.2.c (3) Grouting of Manholes, Wet Wells and Pumping Station Structures - To grout manholes, wet wells and pumping station structures, a special probe-type grout applicator can be used. The grouting operation is performed by physically entering each of the above structures.

5.3.3 Chemical Grouting with Polyurethane Foam

5.3.3.a Properties of the Urethane Foam

The polyurethane foam grout is normally known as 3M Brand Elastomeric Sewer Grouting Compound. The grout is a liquid urethane prepolymer with a specific weight of 9.15 pounds per gallon and a viscosity of 300-350 centipoises at 70° F [12].

When mixed with an equal amount of water, the grout initially foams and then cures to a tough, flexible cellular rubber. The first stage of the reaction is referred to as the "foam time", "induction time" or "cream time" and the second stage is called "cure time", "set time" or "gel time". Both the foam time and the cure time are temperature-dependent. Generally, the higher the temperature, the shorter the reaction times. An accelerator, which is a water-soluble amine, is usually added to the mixing water to reduce the foam and cure times. When a 0.4% accelerator is added, the foam time and cure time at 40° F are 45 seconds and 5.5 minutes, respectively, and, at 100° F, they are 15 seconds and 2.5 minutes, respectively.

The cured grout has a tensile strength of 90 psi and elongation of 800%. Since the grout contains only about 15% of the solvent initially, the linear shrinkage upon drying is only 15%. Cyclic wetting and drying conditions do not substantially affect the grout. The grout is resistant to most organic solvents, mild acids and alkalies.

The unreacted polymer solution is toxic and flammable. Breathing of its vapor and contact with eyes, skin and clothing should be avoided. The container of this solution should be kept away from sparks, heat and flame.

5.3.3.b General Considerations in Applications

The polyurethane foam can be used for sealing pipe joints, but it cannot be used as a structural repair for broken, crushed or badly cracked pipes. Before grouting, the pipes should be cleaned. There should be no obstacles in the pipes to prevent the passage of sealing packer. The sealing packer can only be used at joints where the pipe wall on each side of the joint can provide continuous contact with the packer.

The grout can be used in places where prolonged dry conditions occur. The sealed joints can accept movement because of high flexibility of the cured grout.

5.3.3.c Applications

5.3.3.c (1) Sewer Grouting - For grouting sewers with the polyurethane foam, procedures similar to those with the acrylamide gel are followed. A sealing packer, similar to the one used for the acrylamide gel, is used for injecting the polyurethane foam. The packer is made of a hollow metal cylinder with three inflatable sleeves covered by a continuous outer sleeve. In operation, the packer is positioned on the joint to be grouted with the aid of a television camera and its end sleeves are inflated. The polymer and water are then introduced into the space created between the two inflated sleeves, and the foam time begins. At the end of the foam time, the center sleeve of the packer is inflated, forcing the grout into the pipe joint. After the cure time ends, the sleeves of the packer are deflated and the packer is moved to the next joint.

To determine the integrity of the joints before and after the grouting, a water testing system rather than an air testing system is usually used for the pressure testing.

5.3.3.c (2) Manhole Grouting - The polyurethane foam can also be used to grout the leaking joints and cracks in the manholes. A probe-type applicator is usually used to inject the grout directly into the leaks. The grouting is performed by physically entering the manhole.

5.4 PIPE LINING WITH POLYETHYLENE PIPE

5.4.1 Introduction

This sewer rehabilitation technique is commonly called slip-lining. It involves the pulling of a polyethylene pipe through a straight section of sewer line to replace the latter. The following technical advantages are associated with this method [9]:

- For installation, the excavation is less than that required for complete pipe replacement.
- The installed pipe will have low joint leakage since all joints are butt-fusion welded.
- The smooth inner surface of the polyethylene pipe offers very low resistance to flow.
- The polyethylene pipe is corrosion- and abrasion-resistant.
- The pipe is capable of deflection and movement without breaking.

Because of these advantages, the slip-lining technique may be considered under one or more of the following sewer conditions:

- Extensively cracked pipe, especially if the pipe is constructed in unstable soil conditions;

- Deteriorating pipe having shallow grade, septic conditions and corrosive liquids;
- Pipe with massive and destructive root intrusion problems;
- Pipes in locations where the excavation/replacement technique is not applicable.

5.4.2 Installation Equipment

The following equipment is required for the insertion of the polyethylene pipes into sewers:

- Joining equipment (heat fusion rig)
- Pulling head (nose cone)
- Winch
- Rollers
- Proofing tool
- Grout tank and pump

The joining equipment is used to join the standard polyethylene pipe sections (usually 40 feet in length) aboveground into a continuous pipe of the desired length. The joints are made by aligning the pipe sections on the joining equipment, heating the ends of the pipes and butting the heated ends together. The formed joints are normally stronger than the rest of the pipe and completely waterproof. The pulling head is utilized to facilitate the pulling of the pipe into the sewer. One end of the pulling head is attached to the pipe to be pulled while the other end is attached to the pulling cable. The winch, consisting of a power operator and a pulling cable, is used to pull the pipe. The rollers are used to facilitate the movement of the pipe aboveground during the pull. The proofing tool is utilized to make certain that the proposed liner can pass through the sewer without difficulties. The proofing tool can be fabricated with pulling heads on both ends from a piece of pipe of the same diameter as the one to be inserted and of a length equivalent to two sections of the sewer (normally 8 feet). The grouting tank and pump are used to grout the annular space between the pipe and manhole connections to prevent groundwater migration. When greater structural strength is desired, the annular space in the entire manhole-to-manhole distance can also be grouted.

5.4.3 Installation Procedures

(a) Clean and inspect the sewer to determine the structural conditions, obstructions, offset joints, intruding service connections, size and grade. Determine the applicability of the slip-lining technique to the specific sewer lines being considered
Evaluation Survey Phase).

(b) Determine the size and wall thickness of the polyethylene pipe to be inserted. Remove all obstacles in the sewer, such as deposits, protruding laterals and root intrusion. Pull the proofing tool through the sewers to make certain the proposed pipe size is feasible.

(c) Establish the excavation points on the basis of location of the lines to be slip-lined, pulling distances and traffic conditions. The locations of the excavation points should be such as to minimize traffic disruption. The number of excavations can be reduced by planning to insert the pipe in both directions from a single opening. Normally, a pipe length of 2-3 manhole sections can be lined from a single excavation.

(d) Excavate to expose the sewer and remove the crown of the sewer. The access ditch should be long enough to avoid imposing a bending radius of less than 35-40 times the outside diameter of the pipe liner during insertion. The ditch is sloped gradually from the ground surface to the top of the sewer. The width of the ditch should be sufficient to allow the entry of the workmen. Sheathing and bracing requirements would depend on depth and ground conditions.

(e) Join the polyethylene pipe sections to the desired length at the job site and attach the pulling head to one end of the joined pipe sections.

(f) Run the pulling cable through the sewer pipe and connect it to the pulling head. Pull the pipe liner through the sewer pipe steadily. The annular clearance between the liner and the pipe is usually sufficient to permit normal sewage flow during installation. However, if a high sewage flow is anticipated, sewer bypasses should be provided before installation. Once in place, allow the pipe to reach ground temperature.

(g) Cut in and connect the service connections to the pipe liner. (See Section 5.4.4 for procedures.)

(h) If pulling has been carried out in both directions from the same opening, the adjoining pipe ends should be touching together, wrapped and encased in concrete. Alternatively, the connections can be made by using sleeves extending at least one foot beyond the butted ends and strapped into position.

(i) Grout the annular space between the pipe and the manhole connections. Grouting of the annulus between the liner and the pipe is usually not required if the liner is strong enough to withstand the anticipated loads in the event of the collapse of the pipe.

(j) Backfill and compaction of the excavation.

5.4.4 Methods for Connecting House Service Lines

Three methods have been developed for connecting the house service lines to the newly inserted polyethylene pipe liners in sewers [13]:

- Remote connector
- Heat-fusion saddle
- Tapping saddle

5.4.4.a Remote Connector

This method is most suitable for application under the following conditions:

- Access to the house service line is relatively shallow;
- Existing house service line is large enough and sufficiently straight to permit insertion of a new 4-1/2-inch (outside diameter) polyethylene pipe.

Using this method, the connection can be made with minimum excavation as follows:

(1) Locate the point where the house service line leaves the shallow burial and starts dipping down to connect with the main sewer.

(2) Excavate to expose the service line at this turning point and break away the shoulder of the turn in the pipe to create an access opening.

(3) Insert a cutting tool down the line through the access opening to cut a hole into the new pipe liner in the main sewer.

(4) After the cut is completed, insert a piece of 4-1/2-inch polyethylene pipe of appropriate length down to the main sewer. The connection end of this pipe is butt-fused with an expandable fitting. The fitting fits into the hole previously cut into the pipe liner and is expanded into place by using a heating tool. The fitting has also an integral neoprene gasket which further minimizes the chance of infiltration at the joint.

(5) Remove the excessive protrusion of the new polyethylene service line into the main sewer with a trimming tool.

(6) Connect the upper end of the new service pipe to the service line leading to the house.

(7) Backfill.

(The complete installation is illustrated in Figure 5-3.)

If the existing house service pipe is too small to permit insertion of a 4-1/2-inch (O.D.) polyethylene pipe, or if the pipe route is too tortuous to insert a pipe, the same method can still be used but with some modifications. In this case, a 12-inch hole can be drilled from the ground level to the main sewer line to facilitate the installation of the remote connector. (The installation is illustrated in Figure 5-4.)

5.4.4.b Fusion Saddle

This method involves more excavation than the previous method. The procedure is as follows:

(1) Excavate to the point where the house service line is connected to the main sewer. Expose enough space for two workmen.

(2) Break away a portion of the house service pipe and the old sewer main, and clean the surface area on the newly installed polyethylene liner where the fusion saddle is to be connected.

(3) Heat both the fusion saddle and the surface of the polyethylene liner with the heating tool. When the heating cycle is completed, press the saddle firmly against the melt patch on the liner.

(4) After solidification, cut a hole through the outlet of the saddle fitting into the liner.

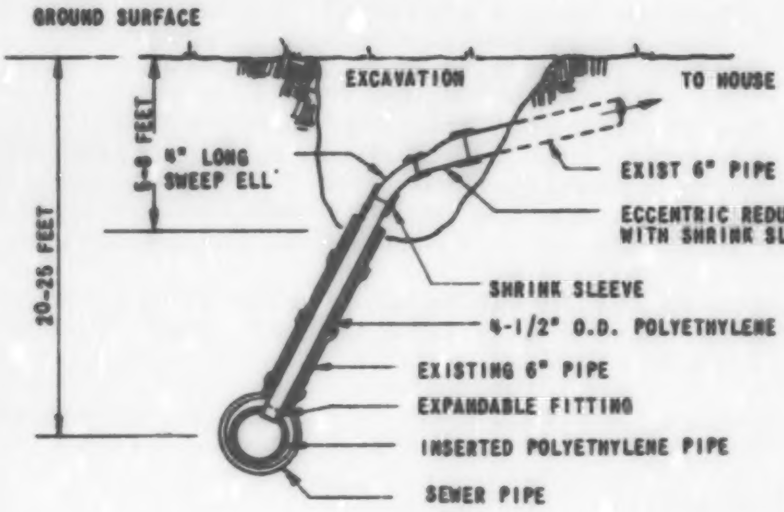

GROUND SURFACE
EXCAVATION
TO HOUSE
5-8 FEET
4" LONG SWEEP ELL
20-25 FEET
EXIST 6" PIPE
ECCENTRIC REDUCER ATTACHED WITH SHRINK SLEEVE
SHRINK SLEEVE
4-1/2" O.D. POLYETHYLENE PIPE
EXISTING 6" PIPE
EXPANDABLE FITTING
INSERTED POLYETHYLENE PIPE
SEWER PIPE

Figure 5-3. Remote Connection of House Service Line through Sewer Pipe [13]

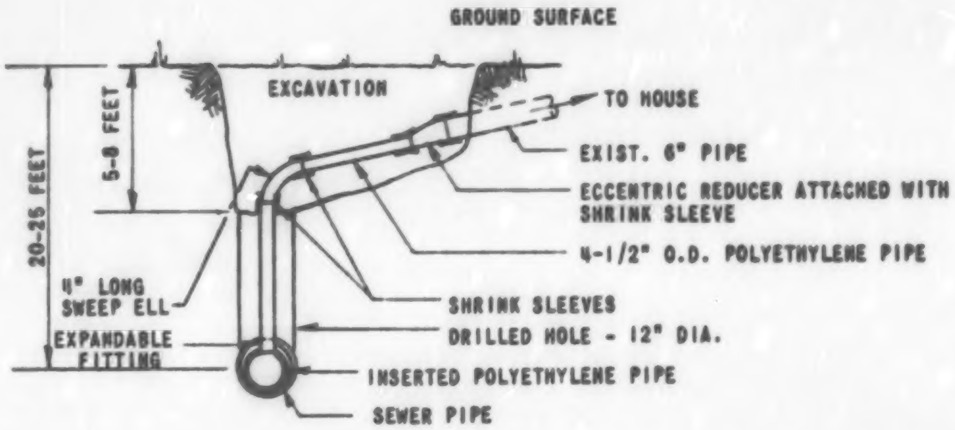

GROUND SURFACE
EXCAVATION
TO HOUSE
5-8 FEET
20-25 FEET
EXIST. 6" PIPE
ECCENTRIC REDUCER ATTACHED WITH SHRINK SLEEVE
4-1/2" O.D. POLYETHYLENE PIPE
4" LONG SWEEP ELL
SHRINK SLEEVES
EXPANDABLE FITTING
DRILLED HOLE - 12" DIA.
INSERTED POLYETHYLENE PIPE
SEWER PIPE

Figure 5-4. Remote Connection of House Service Line through New Drilled Hole [13]

(5) Connect a piece of polyethylene pipe to the outlet of the fusion saddle using a socket heating tool.

(6) Connect the new polyethylene service pipe to the house service pipe leading to the house.

(7) Backfill.

5.4.4.c Tapping Saddle

This method, as follows, uses a full-encirclement saddle fitting to make the connection:

(1) Excavate to the point where the house service line is connected to the main sewer. Expose enough space for two workmen.

(2) Break away a portion of the house service pipe and the old sewer main and clean the surface area on the newly installed polyethylene liner where the tapping saddle is to be connected.

(3) Drill a hole in the polyethylene liner at the point of connection.

(4) Fit the saddle to the hole in the polyethylene liner. Use neoprene gaskets between the underside of the saddle and the liner to provide a tight seal.

(5) Draw the straps around the saddle and the full-encirclement backing to complete the connection.

(6) Use a cement grout or cement-stabilized sand to reinforce the connection area to protect against earth shifting.

(7) Backfill.

5.5 PIPE LINING WITH FIBERGLASS-REINFORCED POLYESTER MORTAR PIPE

5.5.1 Introduction

Similar to the polyethylene pipe, the fiberglass-reinforced polyester mortar pipe can also be used to line the extensively cracked sewer pipes with less excavation than the excavation/replacement technique. This lining method is usually applied to pipes equal to or greater than 21 inches in diameter with no service sewers connected [9]. Because of the nature of the pipe material, it is difficult to cut in and connect the service sewers to this type of pipe. The pipe can be pulled only in straight sections of sewer lines.

The fiberglass-reinforced polyester mortar pipe is corrosion-resistant. The pipe sections are usually 20 feet in length. They are joined by O-ring-sealed inverted bell and spigot joints. The inner surface of the pipe is smooth. However, because of the inverted bell joints, some flow reduction is expected after lining.

5.5.2 Installation Procedures

Before installation, the sewer pipe should be internally inspected and thoroughly cleaned. The liner pipe is inserted by excavating over the sewer and pulling or jacking the pipe upstream against the sewage flow. Sewage flows are normally uninterrupted during the entire operation. The specific procedures are as follows:

(a) Clean and inspect the sewer to determine the structural conditions, obstructions, offset joints, size and grade. Determine the applicability of this lining technique to the sewer lines being considered (completed in the Sewer System Evaluation Survey Phase).

(b) Determine the size and wall thickness of the polyester pipe to be inserted. Remove all obstacles in the sewer, such as deposits, root intrusion, etc. Pull the proofing tool through the sewers to make certain the proposed pipe size is feasible.

(c) Establish the excavation points on the basis of locations of the sewers to be lined, pulling distances and traffic conditions. The locations of the excavation points should be such as to minimize traffic disruption. Pipes are usually pulled upstream against the sewage flow. Therefore, the excavation point should be located at the downstream locations on the sewer lines to be lined.

(d) Excavate to expose the sewer and remove the crown of the sewer. The working pit should be long enough to accommodate the liner sections and the jacking equipment. If the liner sections are to be pulled into the pipe, a shorter pit (approximately 26 feet) would be sufficient. Sheathing and bracing requirements would depend on depth and ground conditions.

(e) Join the liner pipe sections at the job site. Jack or pull the pipe through the sewer steadily. The annular clearance between the liner and the pipe is usually sufficient to permit normal sewage flow during installation. However, if unusually high sewage flow is anticipated, sewer bypasses should be provided before installation.

(f) Grout the annular space between the liner pipe and the manhole connections. Grouting of the annular space between the liner and the pipe is usually not required if the liner is strong enough to withstand the anticipated loads in the event of the collapse of the pipe.

(g) Backfill and compact the excavation.

5.6 PIPE LINING WITH CEMENT MORTAR AND EPOXY MORTAR

Cement mortar and epoxy mortar can be used to internally line round concrete or brick pipes which are still structurally sound. This lining method is generally applied to pipes 24 inches in diameter or larger although it may also be applied to smaller pipes [9]. The cement mortar linings are vulnerable to chemical attack and should not be used in sewers transmitting corrosive liquids. For corrosive environments, the epoxy mortar should always be used. The drawback of this type of lining is that the corrosion caused by hydrogen sulfide may continue underneath the lining.

The mortars are usually machine-applied to the interior surface of the sewer pipes. Before application, the pipe surface should be thoroughly clean, all loose materials should be removed, the sewage flow should be stopped or bypassed, and the water standing in the pipe should be removed. During application, no active infiltration through joints, pipe walls and service connections is allowed. The pipe surface should be dried if the epoxy mortar is used; however, for cement mortar lining, a moist pipe surface is acceptable. The thickness of the lining is usually 3/16 inch to 3/8 inch [9].

CHAPTER 6

COSTS FOR SEWER SYSTEM EVALUATION SURVEY AND REHABILITATION

6.1 INTRODUCTION

The cost data presented in this chapter provides a general guidance for engineers performing the cost-effectiveness analysis in Infiltration/Inflow Analysis. To a limited extent, the data can also be used for conducting the cost-effectiveness analysis in Sewer System Evaluation Survey. The methodology for performing each respective cost-effectiveness analysis has been described previously (Sections 3.4 and 4.6.3).

The limitations of these cost data must be recognized. The costs are mainly a compilation of the data from several reference sources (14, 15, 16, 17) and a number of Infiltration/Inflow Analysis reports submitted to EPA, and reflect the average costs prevailing in mid-1974. Individual costs may vary significantly due to location, site condition, sewer system condition, weather condition, availability of labor force, work requirements, and numerous other factors. Therefore, use of the data presented herein should be limited to preliminary cost estimates. Engineers are encouraged to develop their own cost data from reliable sources to fit the specific conditions of each project at hand.

6.2 SEWER SYSTEM EVALUATION SURVEY COSTS

Table 6-1 shows the costs required for conducting each phase of Sewer System Evaluation Survey, except report preparation. The unit costs presented are the costs required for each foot of gravity sewer actually included in the evaluation survey. The range of costs presented for each function reflects the possible variation of costs for performing the work in different sewer systems. Factors which may affect the costs for each phase of study are shown in Tables 6-2 to 6-5.

Figures 6-1 to 6-24 show the cost curves for the Sewer System Evaluation Survey and for conducting each phase of work in the Evaluation Survey in terms of the following four parameters:

- Total length of gravity sewer in system
- Peak infiltration/inflow

TABLE 6-1

COSTS FOR SEWER SYSTEM EVALUATION SURVEY

Function	Cost, $/foot of sewer
Physical Survey	0.15-0.25
Rainfall Simulation	
Smoke Testing	0.15-0.30
Dyed Water Test	0.25-0.50
Water Flooding	0.25-0.50
Preparatory Cleaning	
6-inch Pipe	0.30-1.10
8-inch Pipe	0.25-0.90
10-inch Pipe	0.30-1.30
12-inch Pipe	0.35-1.70
15-inch Pipe	0.40-2.10
18-inch Pipe	0.50-2.25
21-inch Pipe	0.70-3.50
24-inch Pipe	0.80-4.25
30-inch Pipe	1.15-5.50
36-inch Pipe	1.45-6.80
Internal Inspection	
6-inch Pipe	0.45-1.25
8-inch Pipe	0.35-1.20
10-inch Pipe	0.30-1.15
12-inch Pipe	0.30-1.20
15-inch Pipe	0.30-1.30
18-inch Pipe	0.35-1.40
21-inch Pipe	0.40-1.55
24-inch Pipe	0.50-1.75
30-inch Pipe	0.55-2.00
36-inch Pipe	0.75-2.20

TABLE 6-2

PHYSICAL SURVEY COST CRITERIA

Size of study area
Access to manholes
Manhole opening
Manhole size
Manhole depth
Manhole condition
Hazardous gases in manholes
Cleanliness of manholes and sewers
Pipe size
Depth of flow
Flow rate
Weather conditions
Availability and cost of labor

TABLE 6-3

RAINFALL SIMULATION COST CRITERIA

Access to manholes

Manhole conditions

Hazardous gases in manholes

Cleanliness of manholes and sewers

Pipe size

Depth of flows

Flow rate

Availability of water

Random vs. successive manhole sections

Weather conditions

Availability and cost of labor

TABLE 6-4

SEWER CLEANING COST CRITERIA

Access to manholes

Manhole conditions

Type of manhole construction

Size of manholes

Depth of sewer

Depth of flow

Depth of deposition

Type of deposition

Pipe size

Structural condition of sewer

Length of manhole section

Intruding building sewers

Requirement for transportation and disposal of material removed from the sewer

Distance to disposal site

Traffic control requirement

Availability of water

Degree of root intrusion

Random vs. successive manhole section

Weather condition

Mobilization distance

Availability and cost of labor

TABLE 6-5

INTERNAL INSPECTION COST CRITERIA

Access to manholes

Length of manhole section

Manhole conditions

Hazardous gases in manholes

Depth of sewer

Depth of flow

Flow rate

Pipe size

Pipe cleanliness

Structural condition of sewer

Random vs. successive manhole sections

Flooding conditions

Plugging requirements

Bypass requirements

Terrain

Traffic control requirement

Weather conditions

Documentation requirements

Report requirement

Mobilization distance

Availability and cost of labor

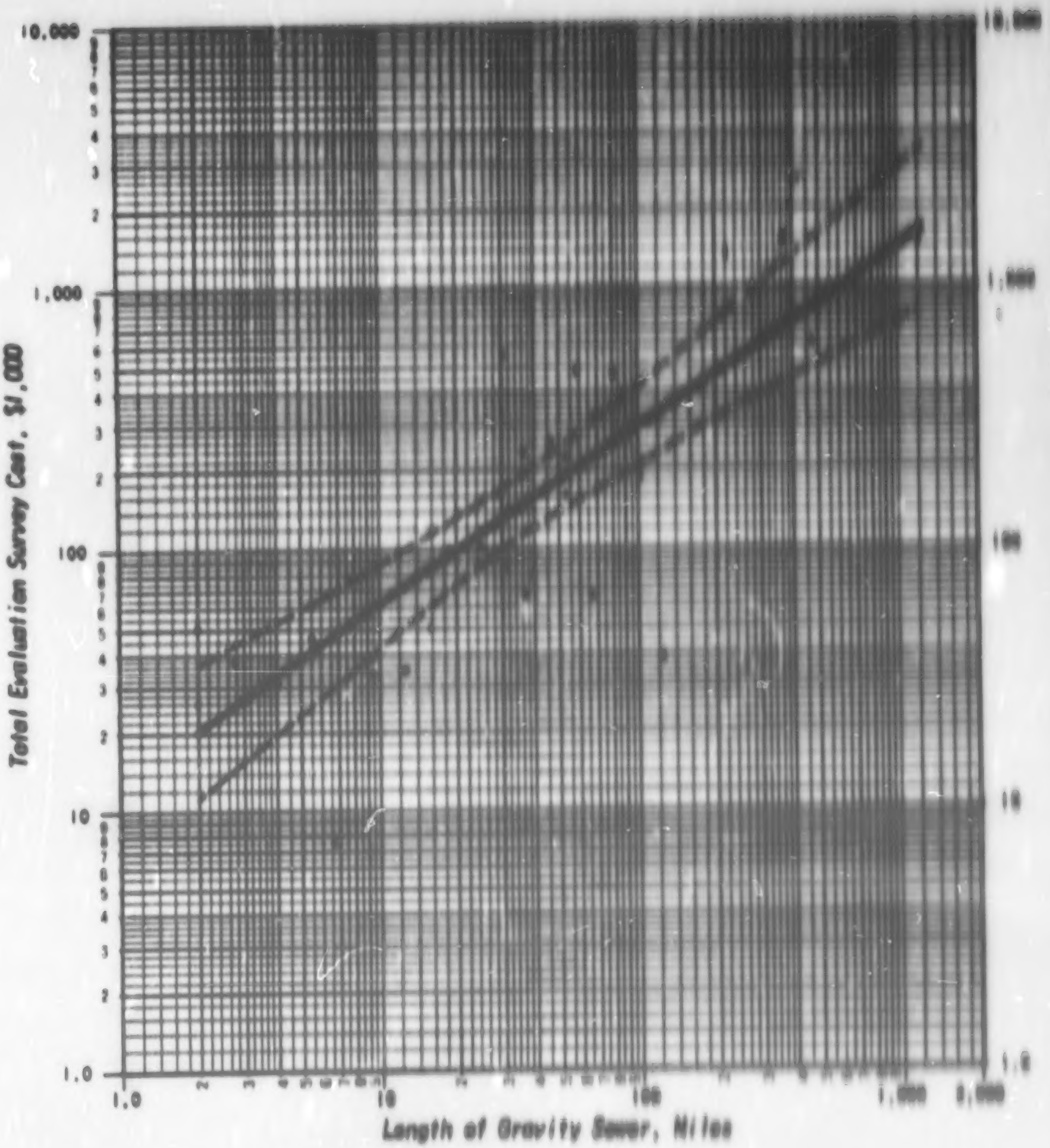


Figure 6-1. Total Evaluation Survey Cost vs. Sewer Length

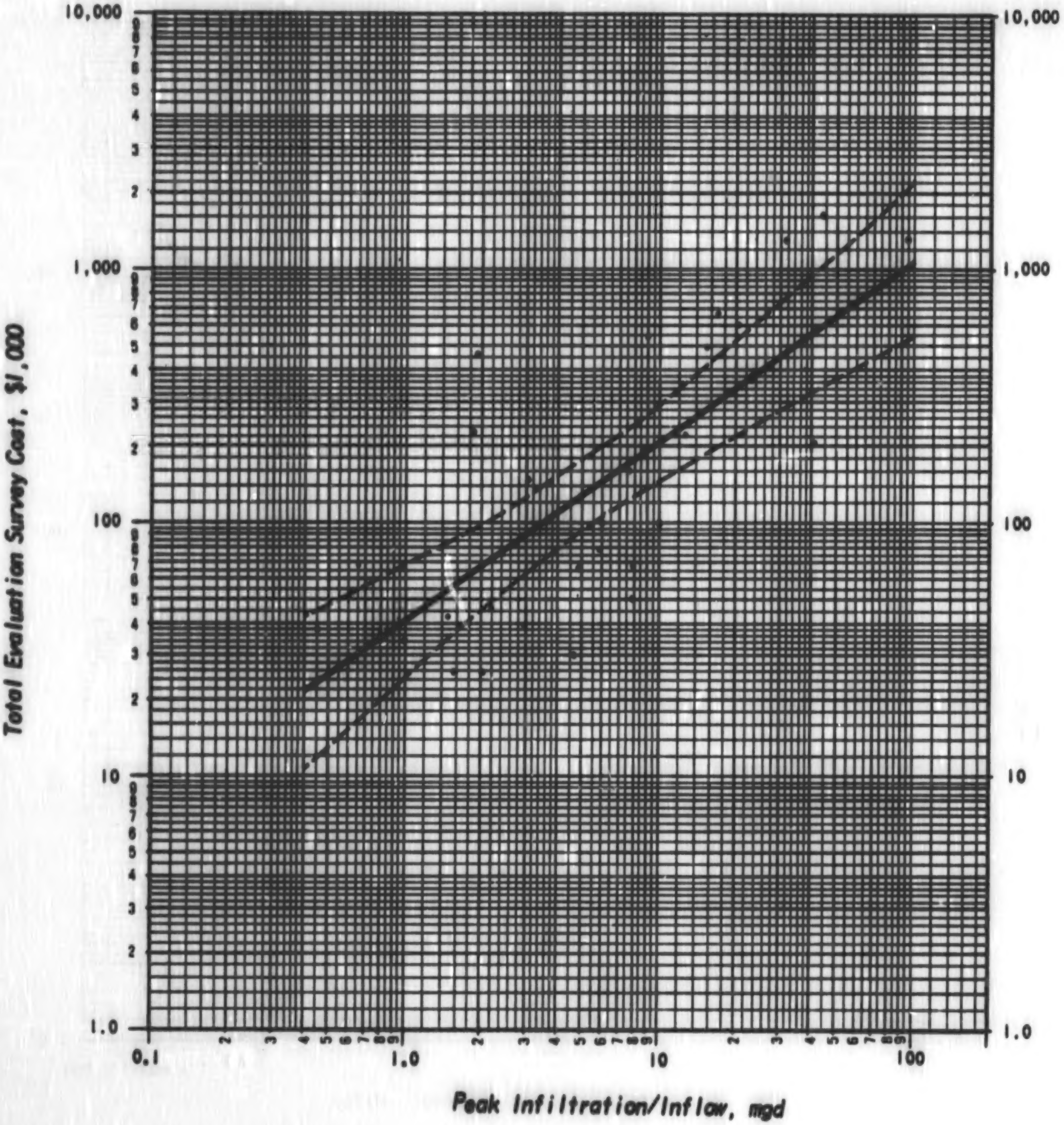


Figure 6-2. Total Evaluation Survey Cost vs. Peak Infiltration/Inflow

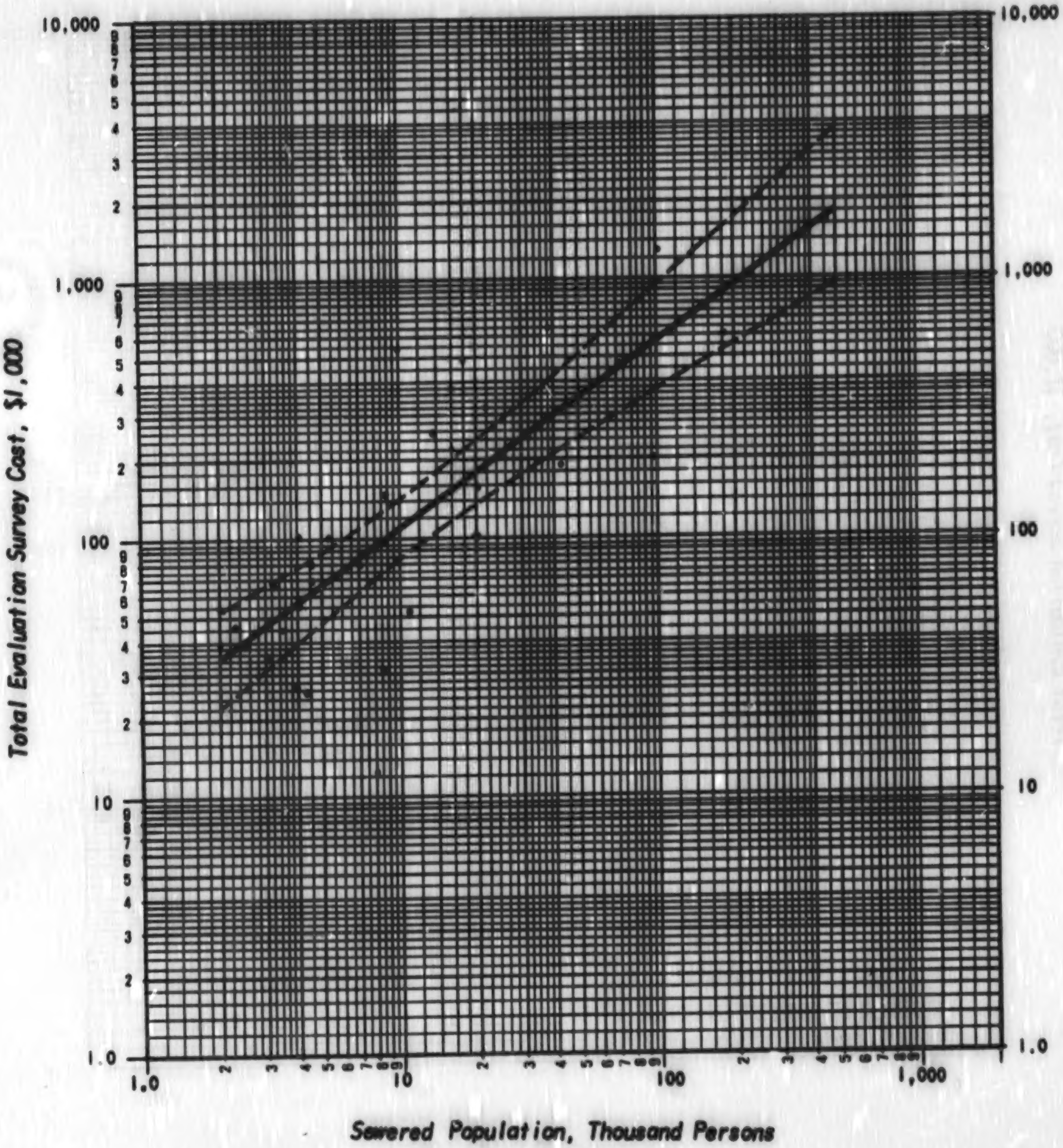


Figure 6-3. Total Evaluation Survey Cost vs. Sewered Population

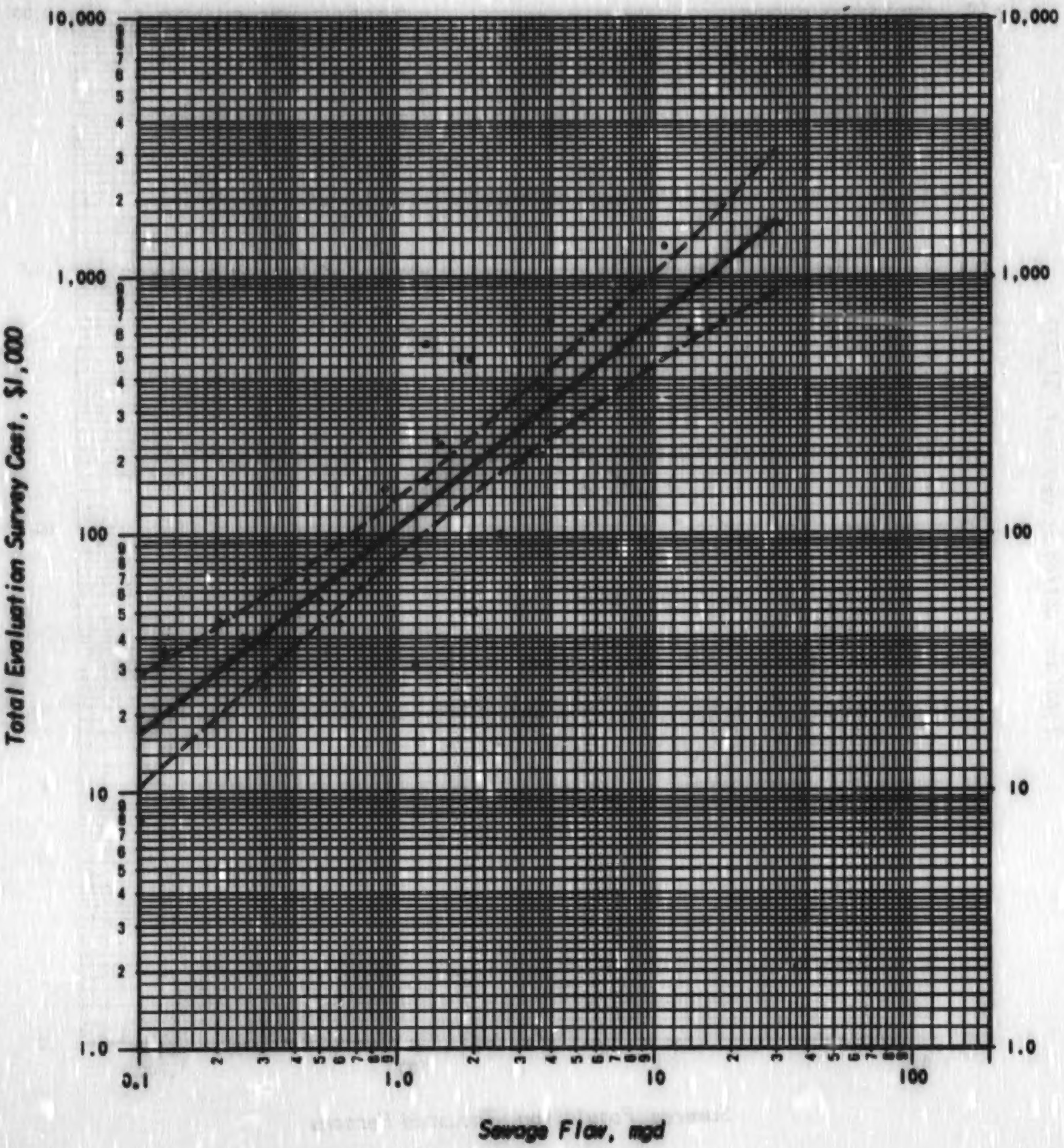


Figure 6-4. Total Evaluation Survey Cost vs. Sewage Flow

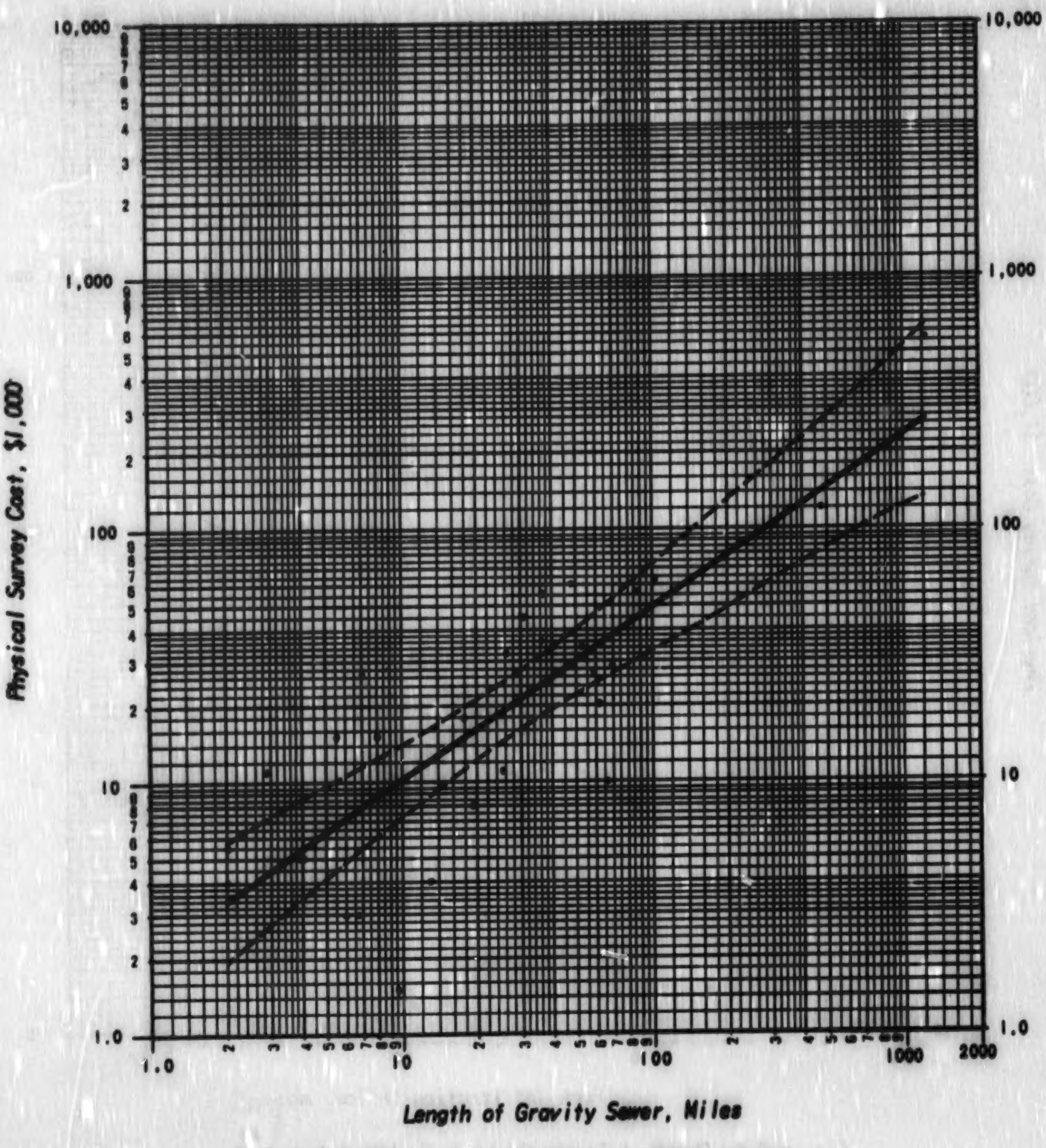


Figure 6-5. Physical Survey Cost vs. Sewer Length

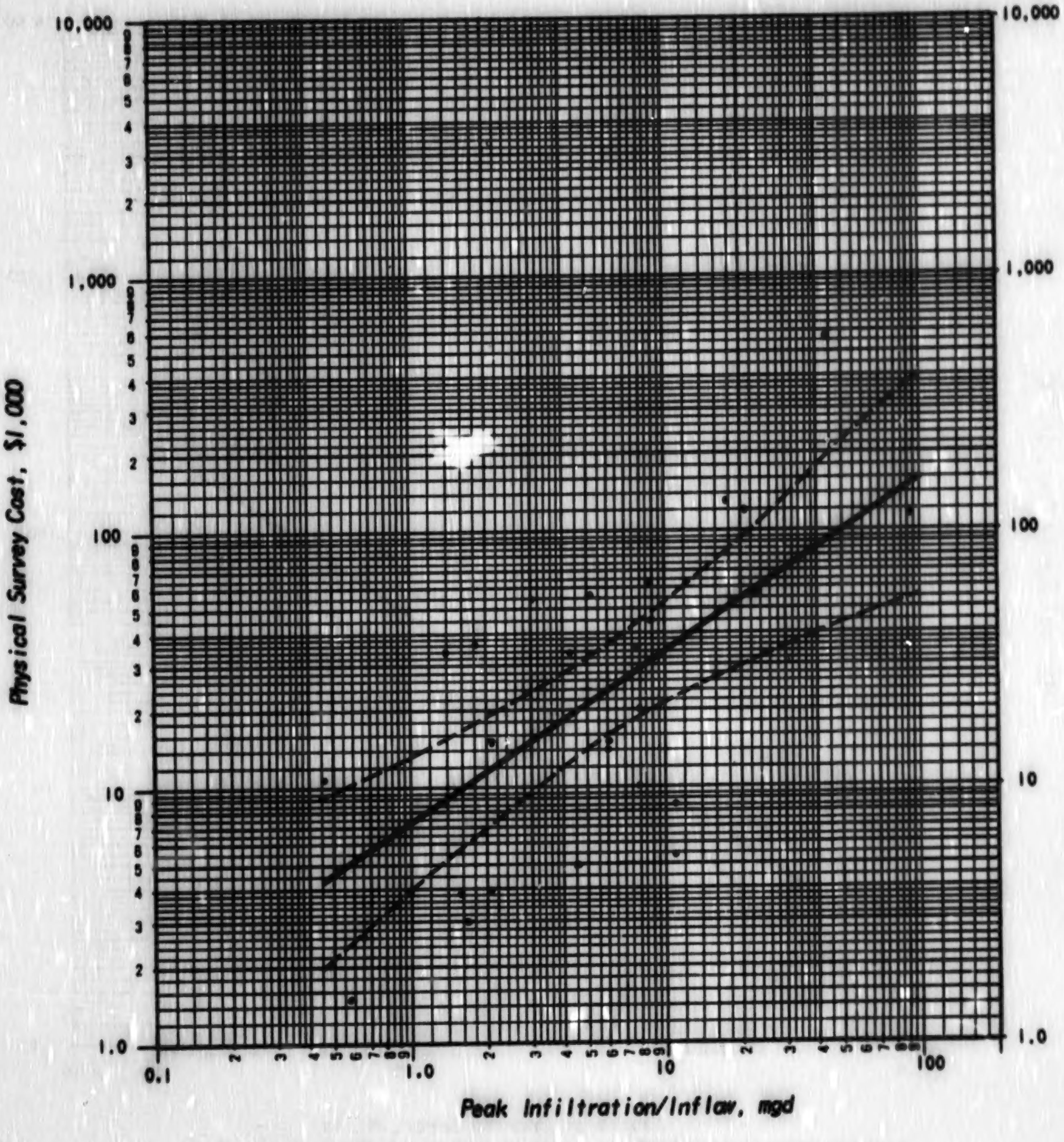


Figure 6-6. Physical Survey Cost vs. Peak Infiltration/Inflaw

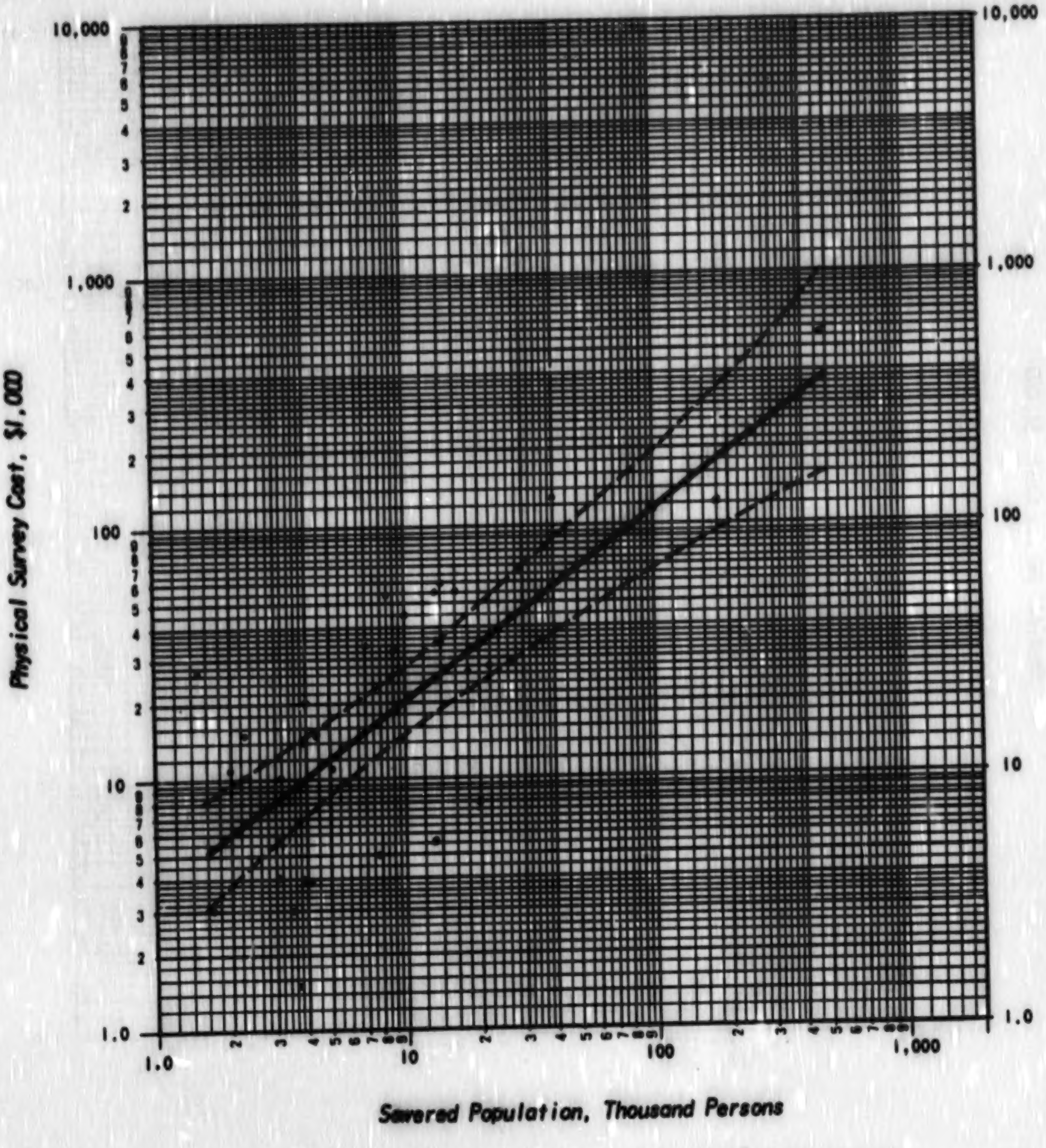


Figure 6-7. Physical Survey Cost vs. Sewered Population

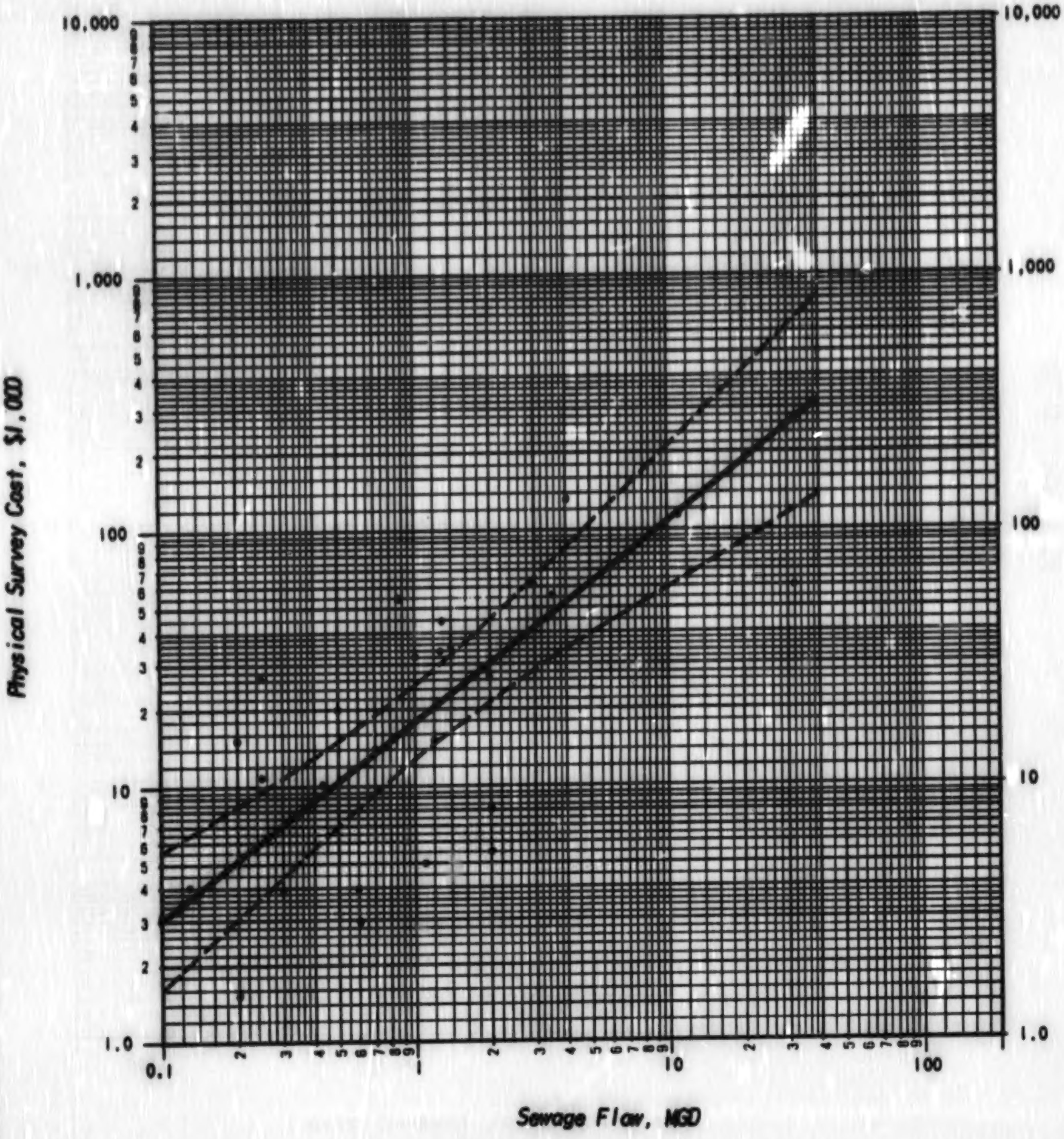


Figure 6-8. Physical Survey Cost vs. Sewage Flow

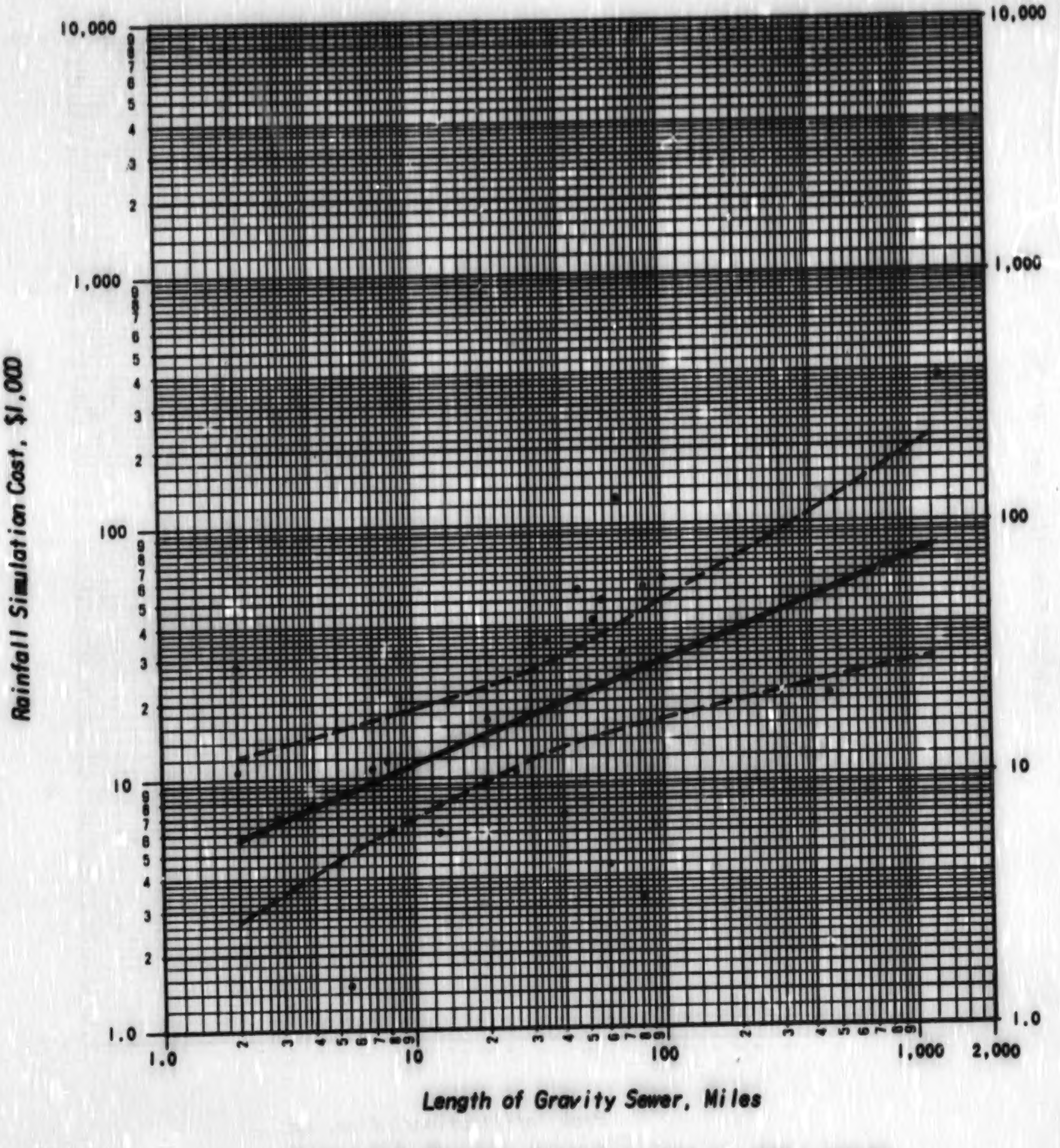


Figure 6-9. Rainfall Simulation Cost vs. Sewer Length

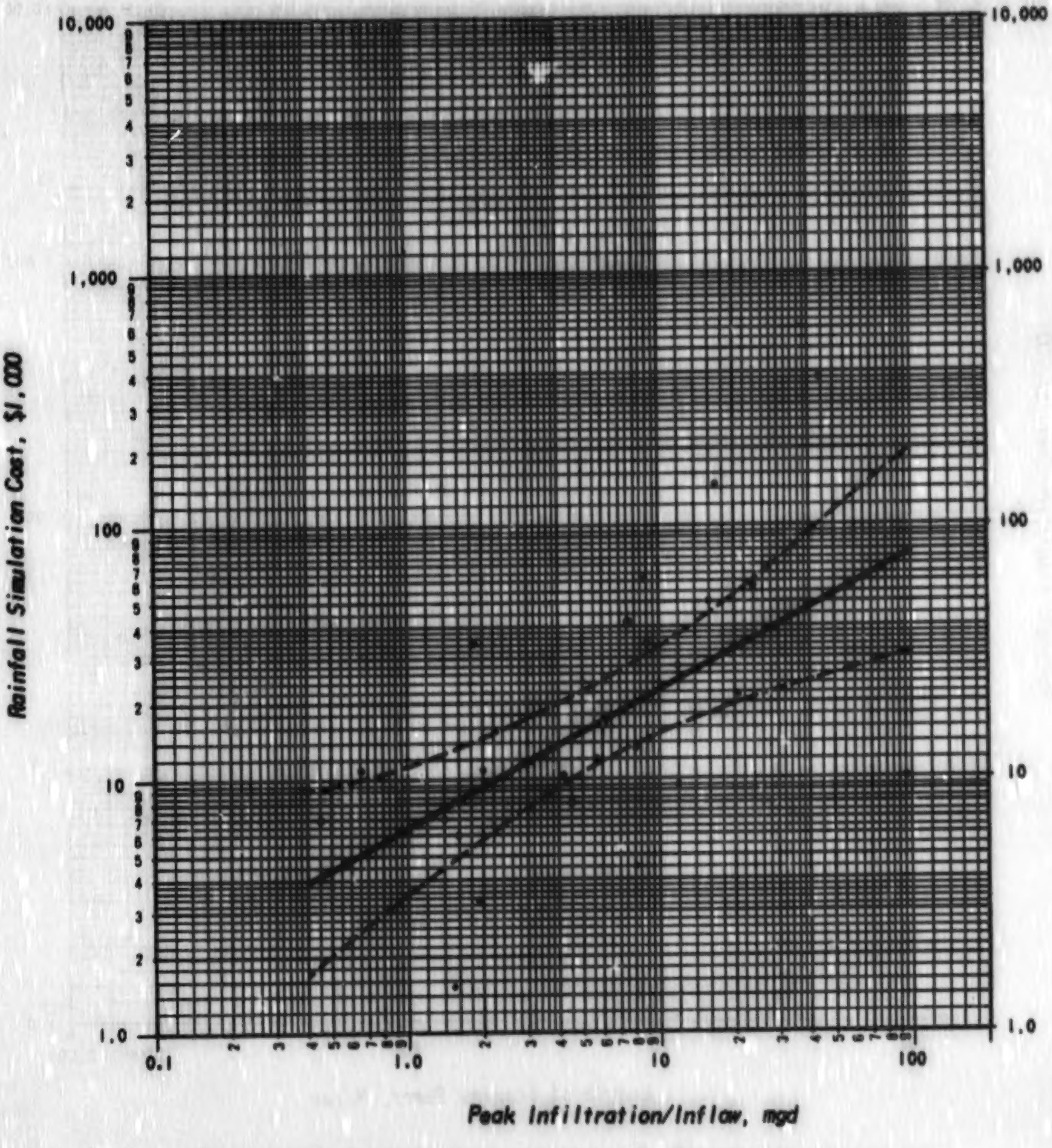


Figure 6-10. Rainfall Simulation Cost vs. Peak Infiltration/Inflow

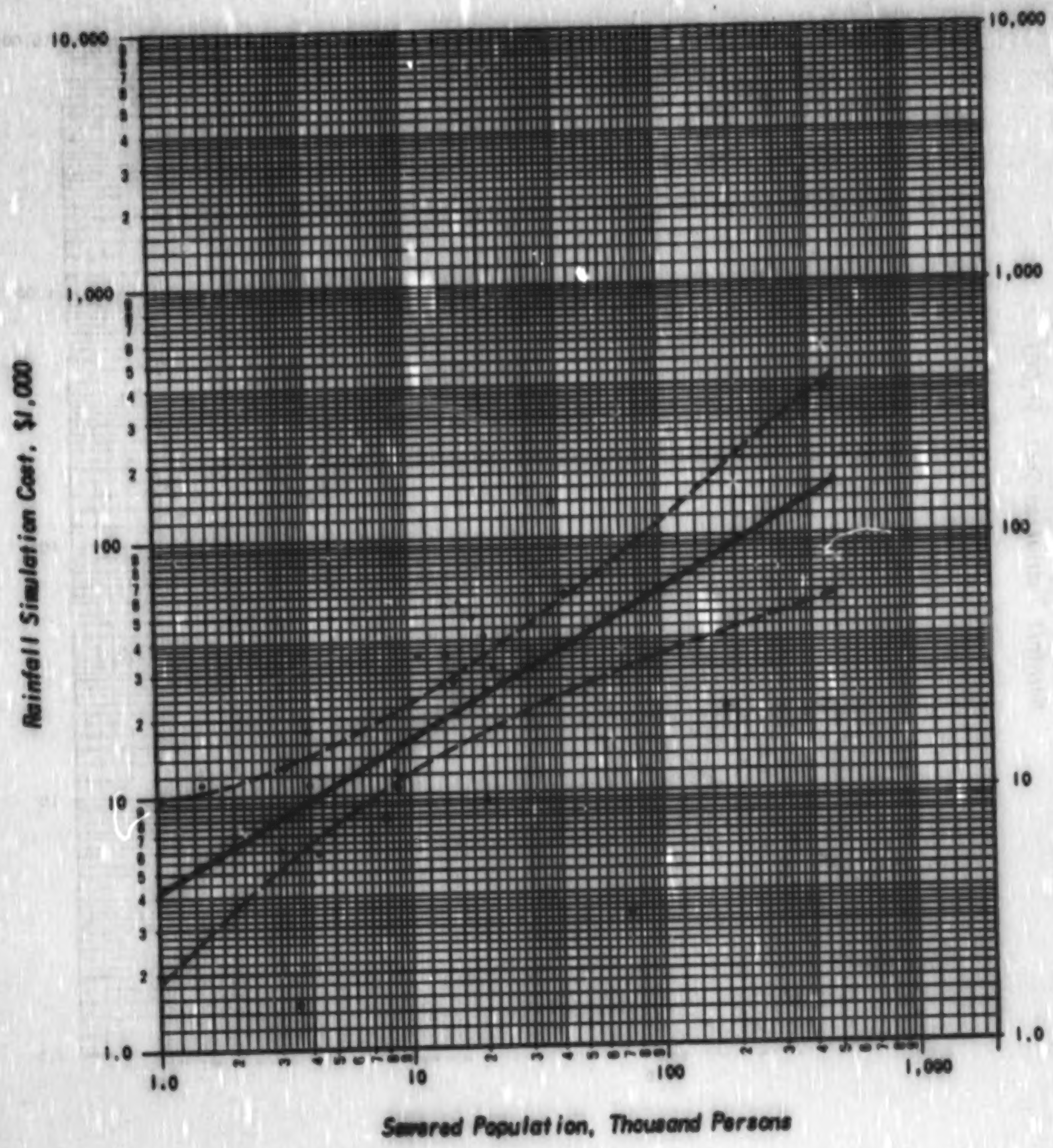


Figure 6-11. Rainfall Simulation Cost vs. Sewered Population

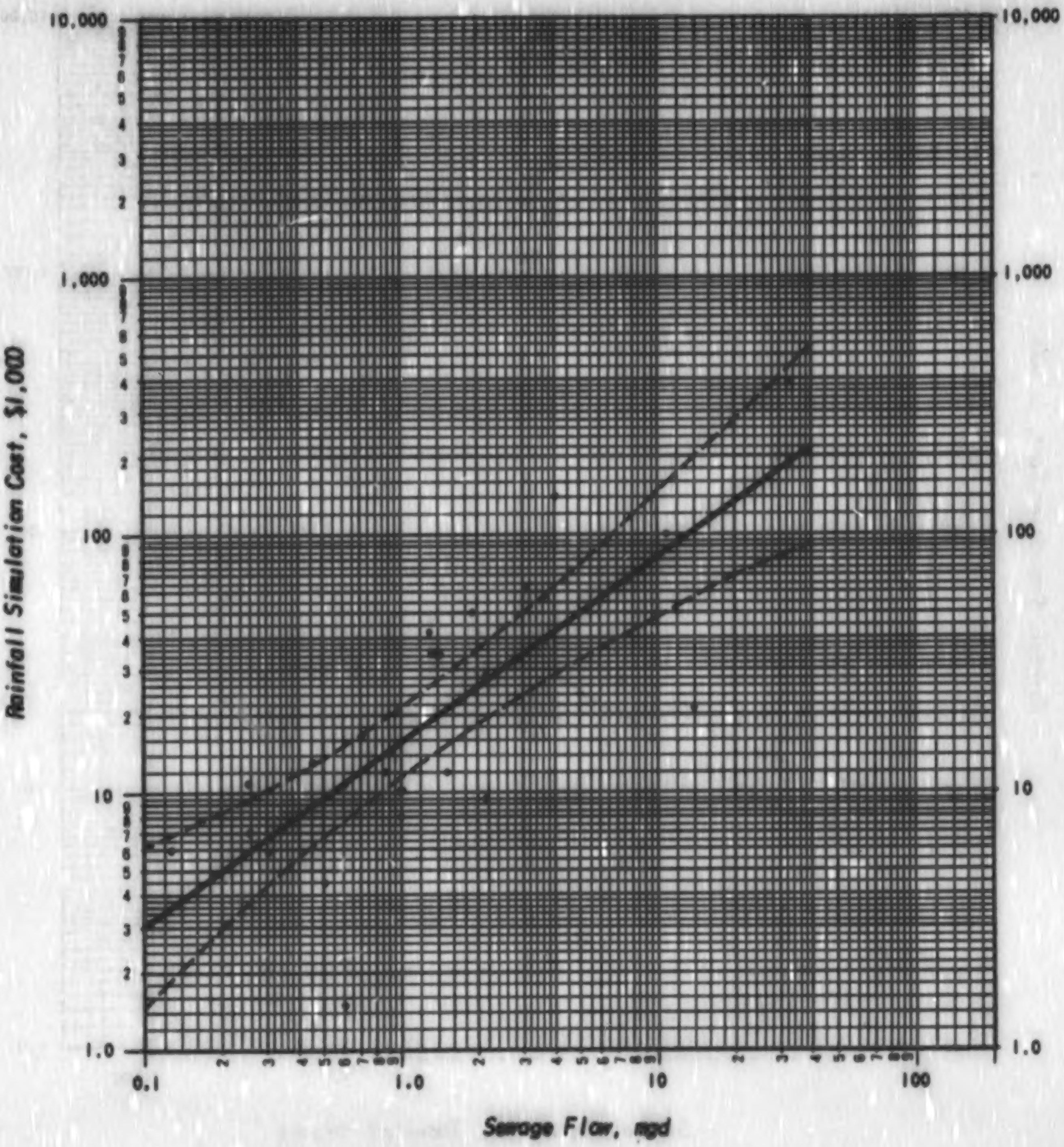


Figure 6-12. Rainfall Simulation Cost vs. Sewage Flow

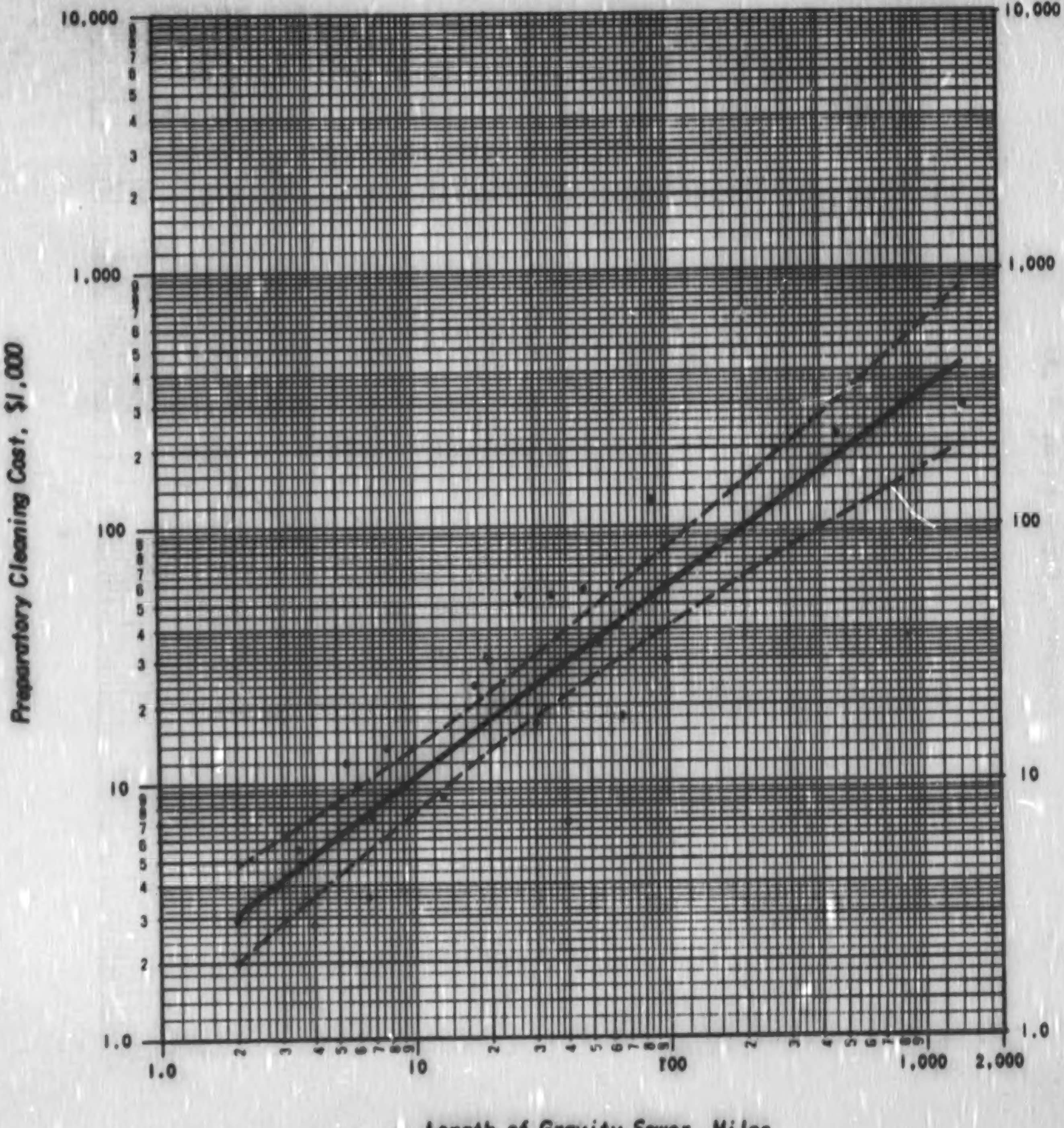


Figure 6-13. Preparatory Cleaning Cost vs. Sewer Length

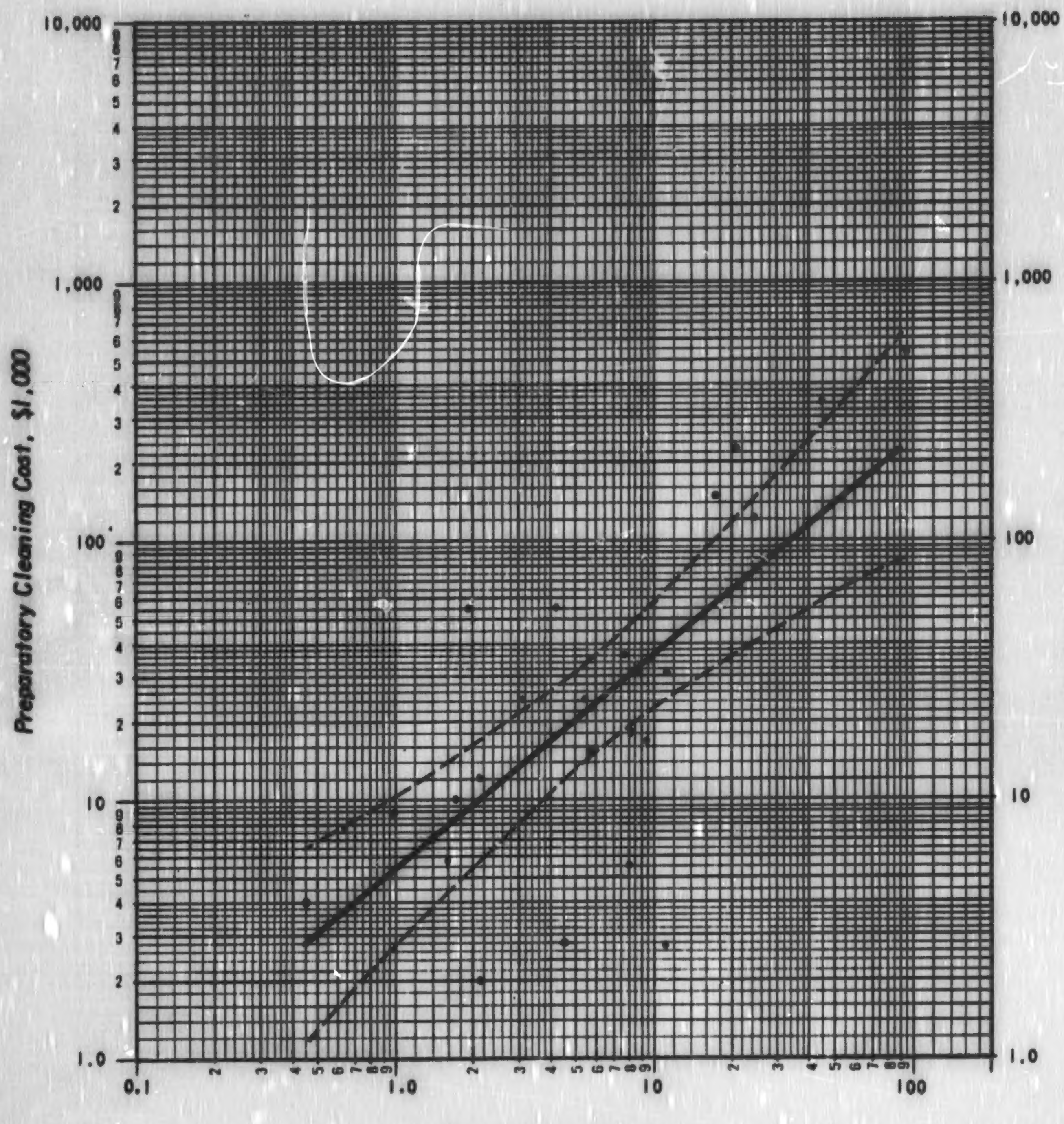


Figure 6-14. Preparatory Cleaning Cost vs. Peak Infiltration/Inflow

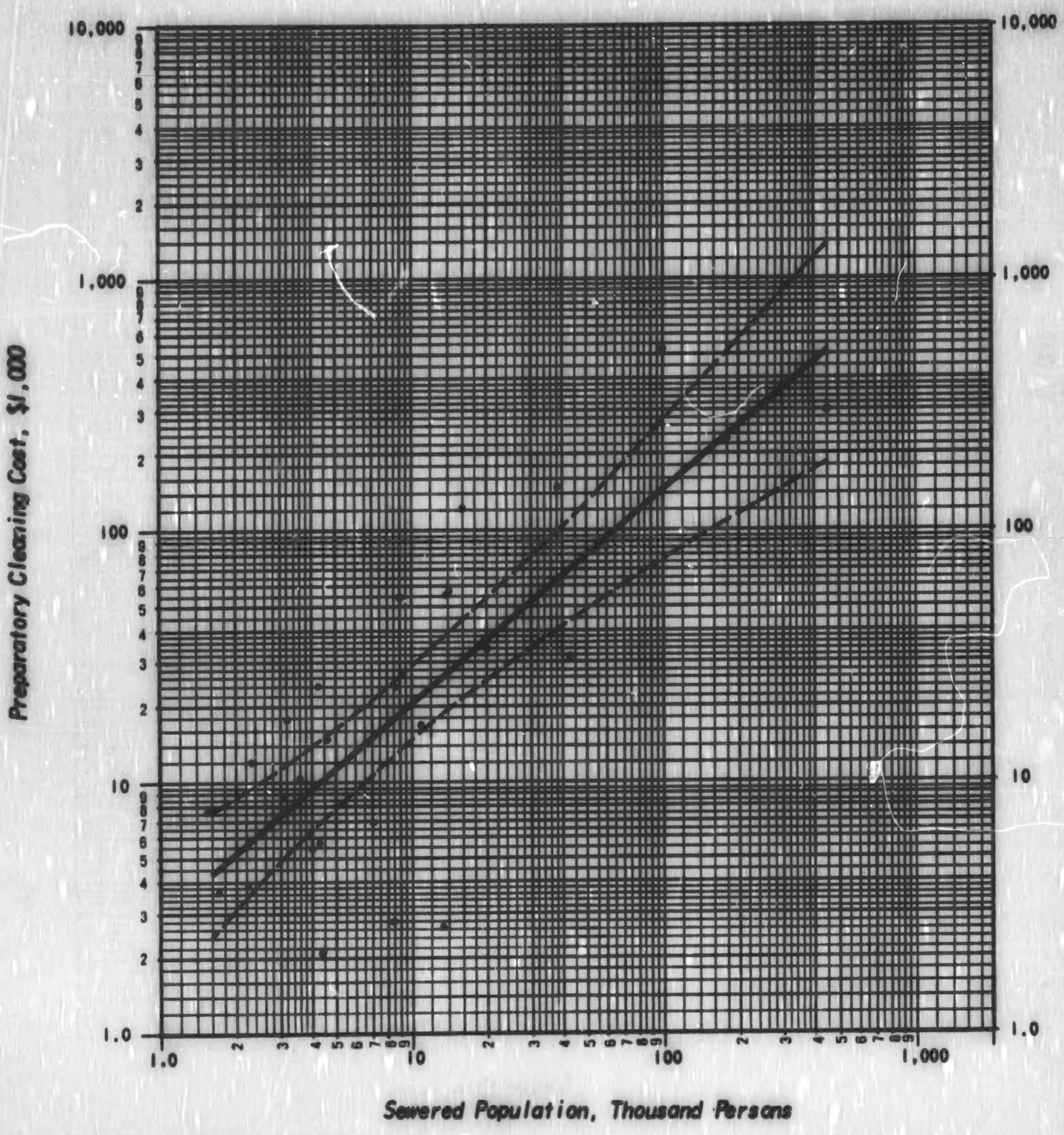


Figure 6-15. Preparatory Cleaning Cost vs. Sewered Population

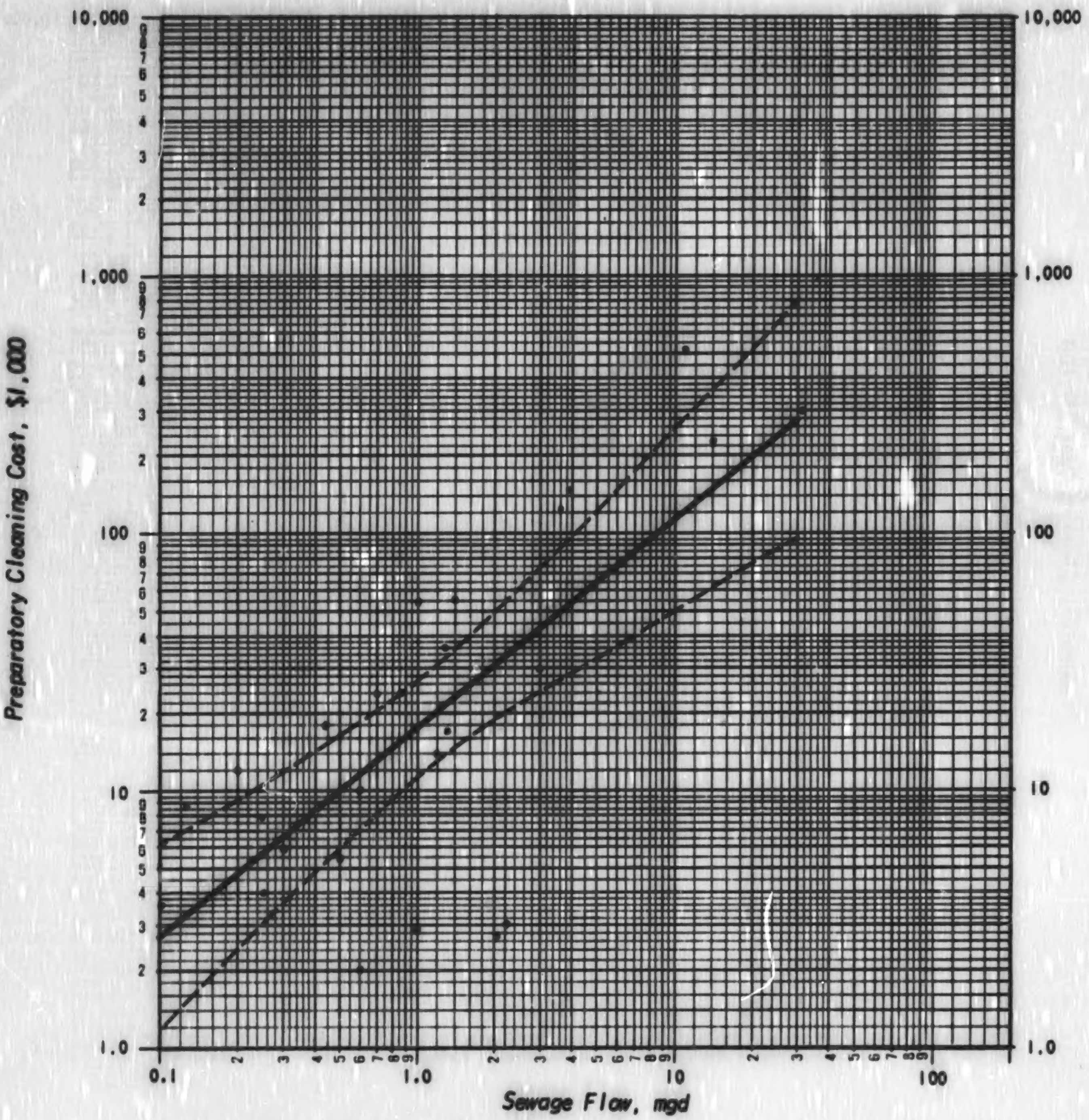


Figure 6-16. Preparatory Cleaning Cost vs. Sewage Flow

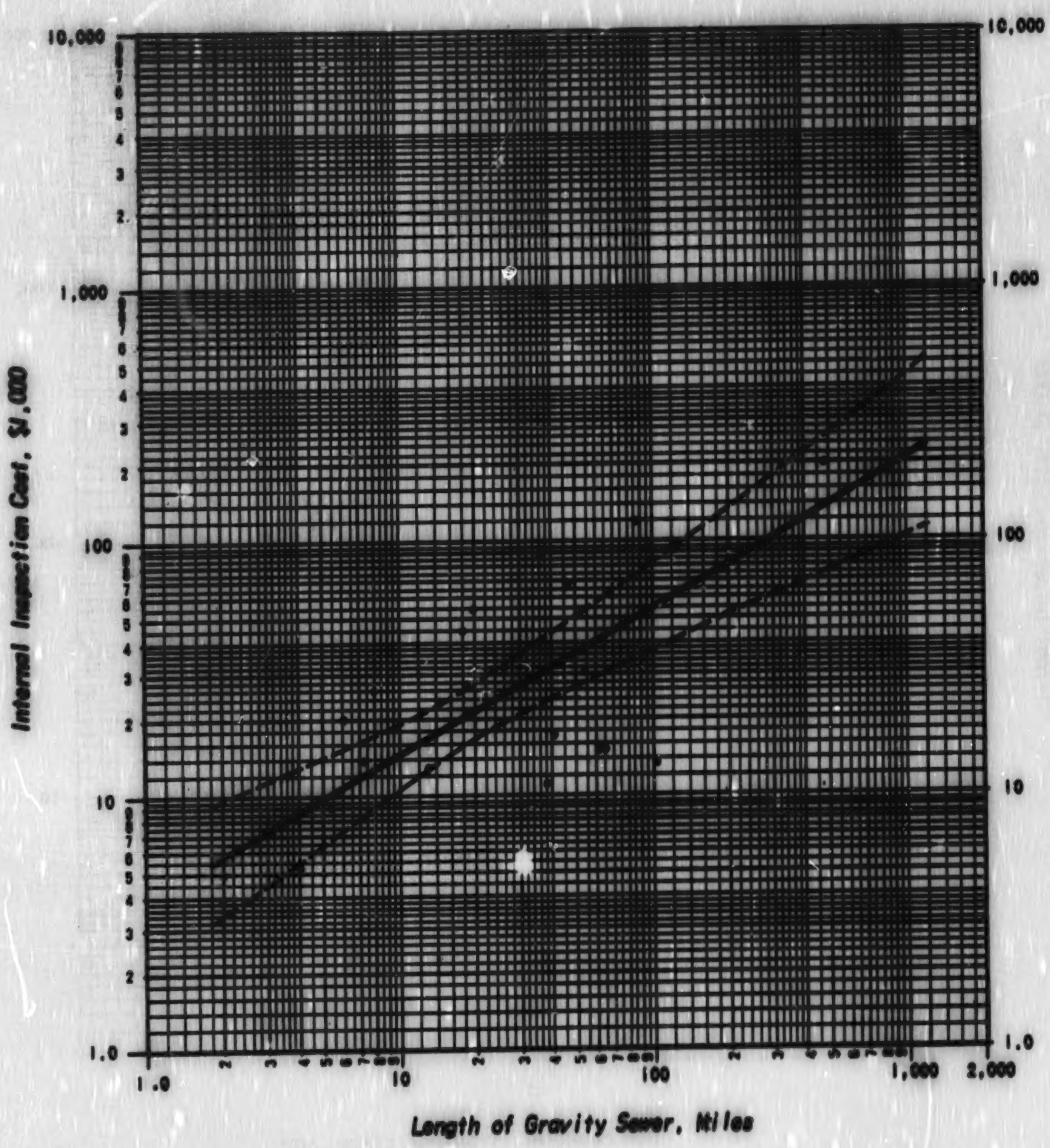


Figure 6-17. Internal Inspection Cost vs. Sewer Length

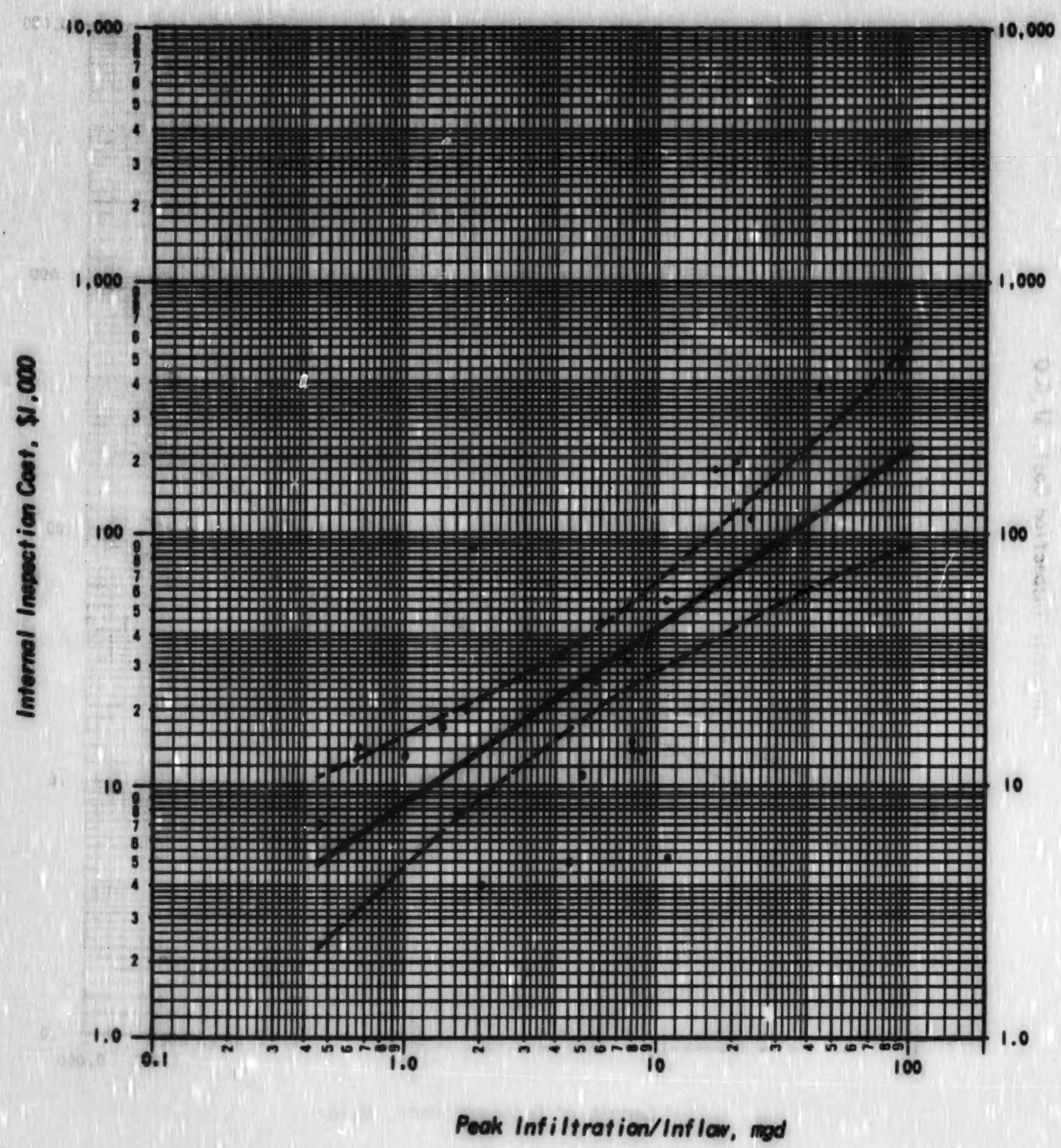


Figure 6-18. Internal Inspection Cost vs. Peak Infiltration/Inflow

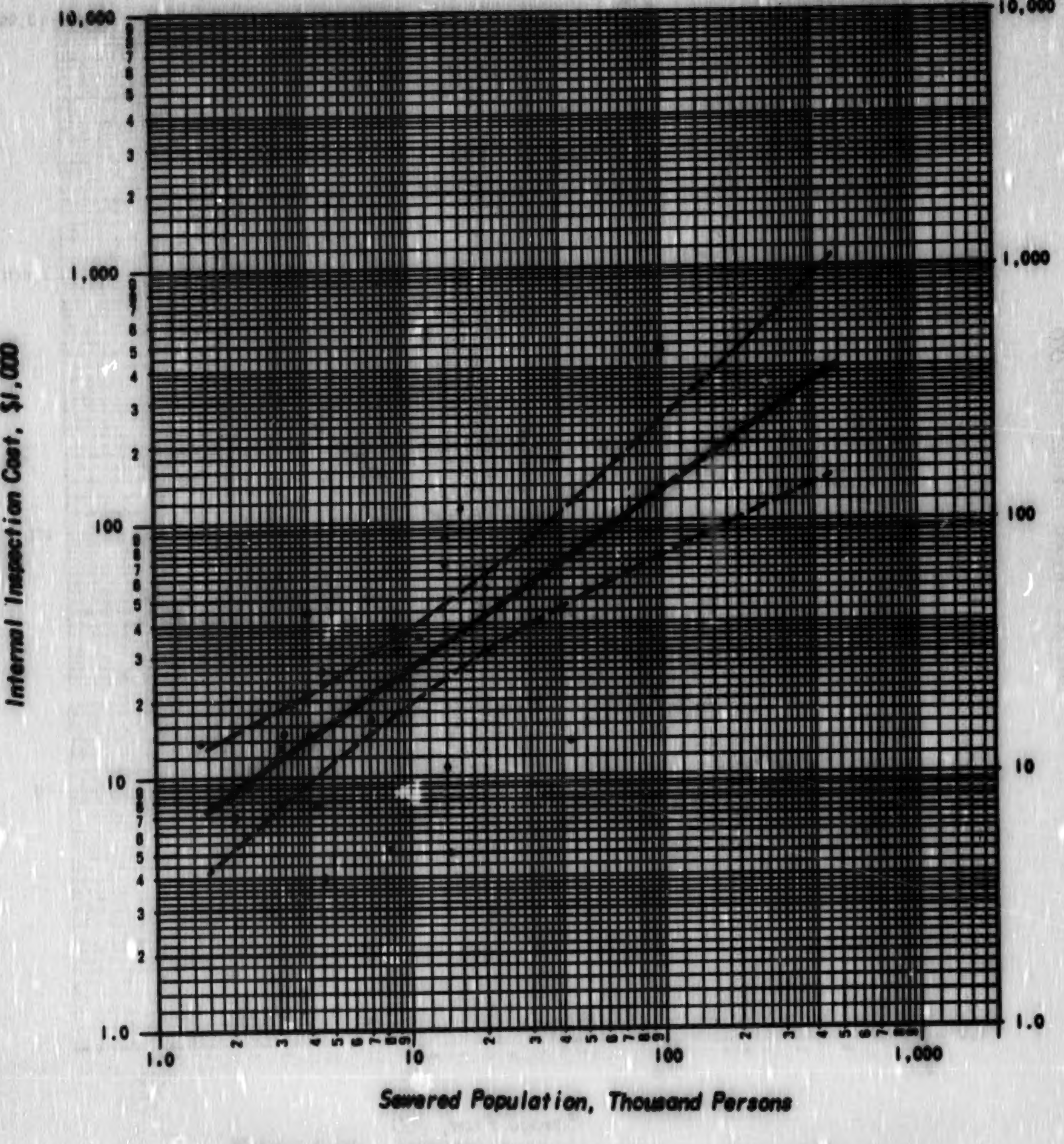


Figure 6-19. Internal Inspection Cost vs. Sewered Population

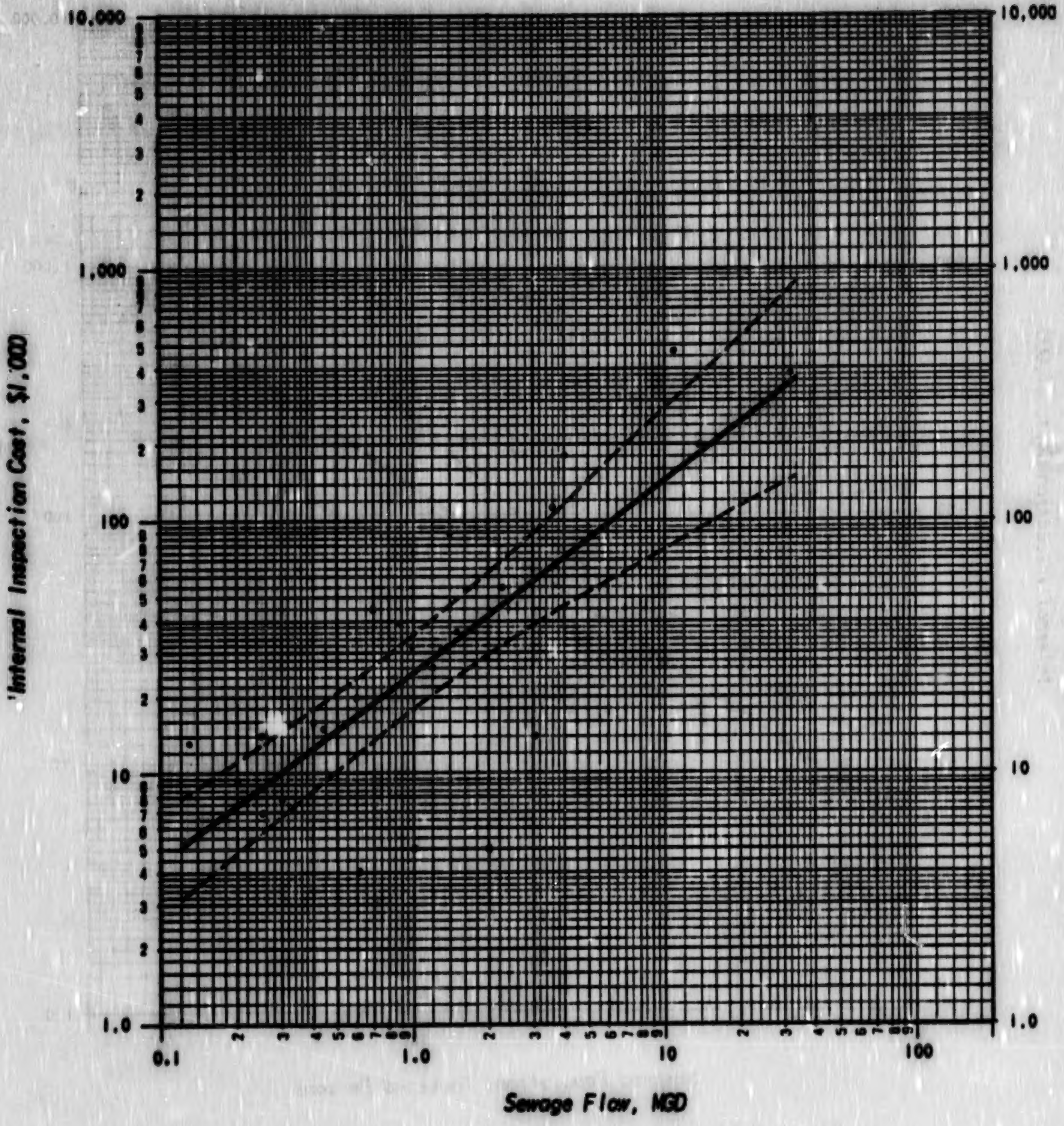


Figure 6-20. Internal Inspection Cost vs. Sewage Flow

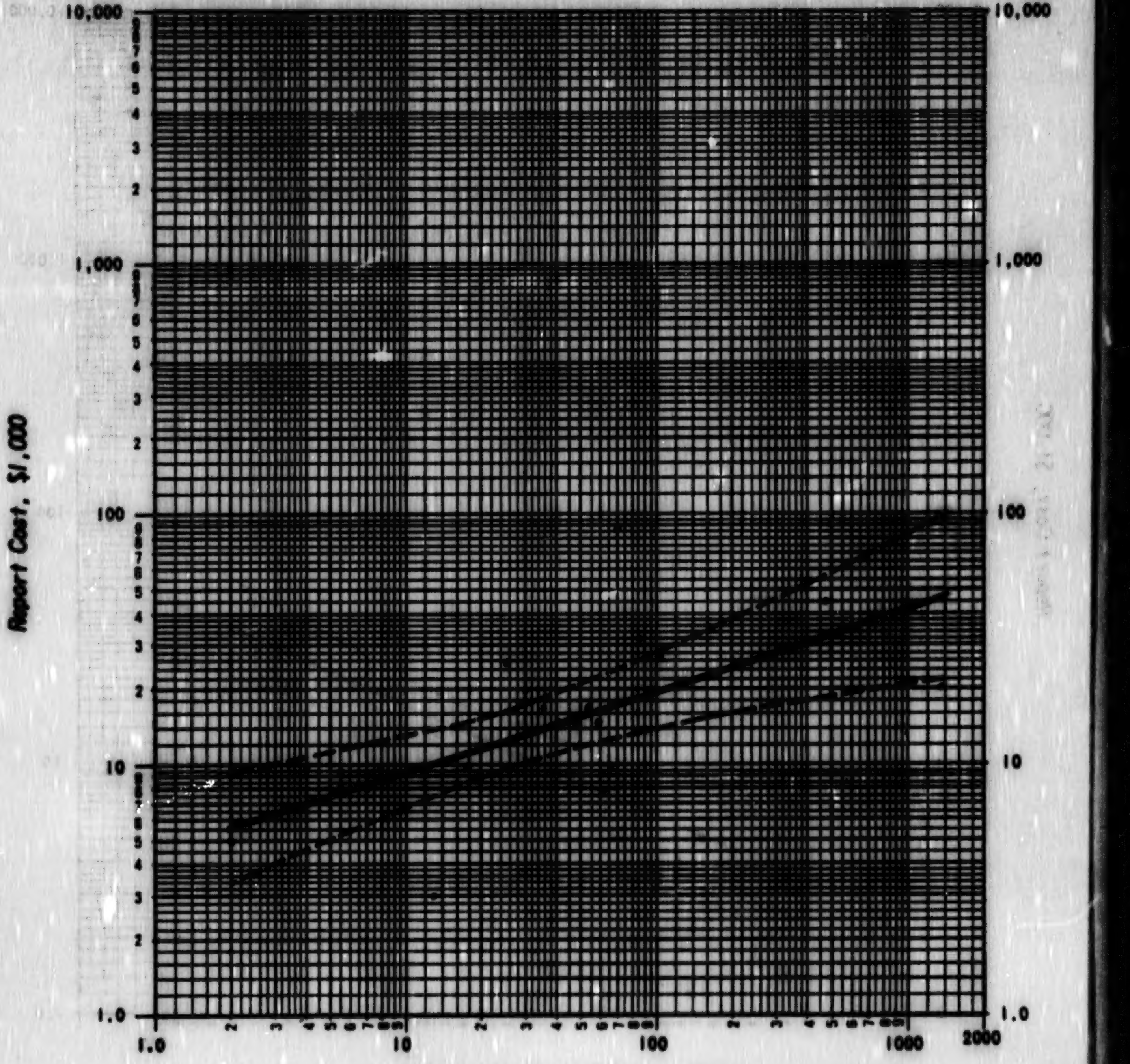


Figure 6-21. Report Cost vs. Sewer Length

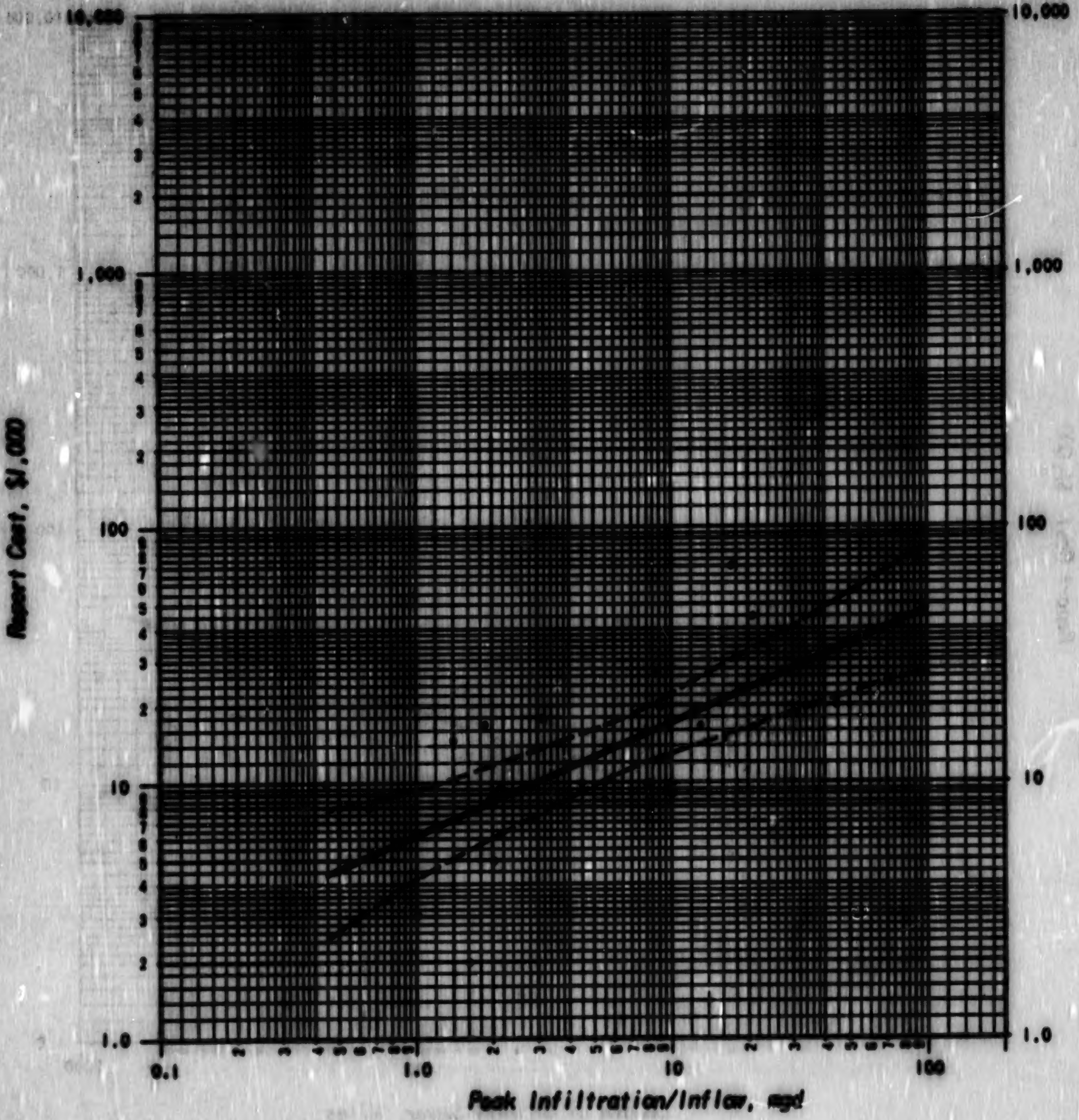


Figure 6-22. Report Cost vs. Peak Infiltration/Inflow

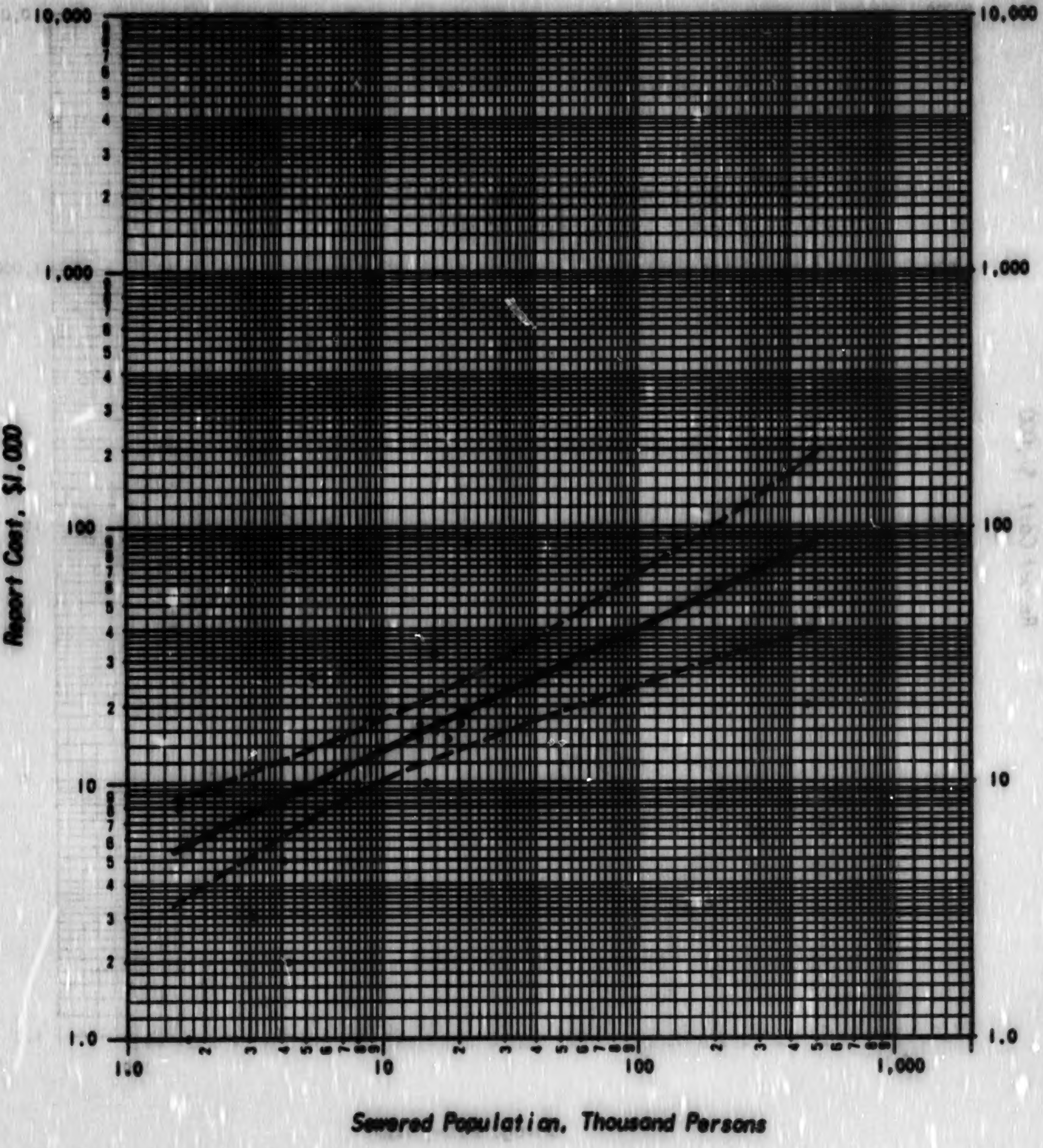


Figure 6-23. Report Cost vs. Sewered Population

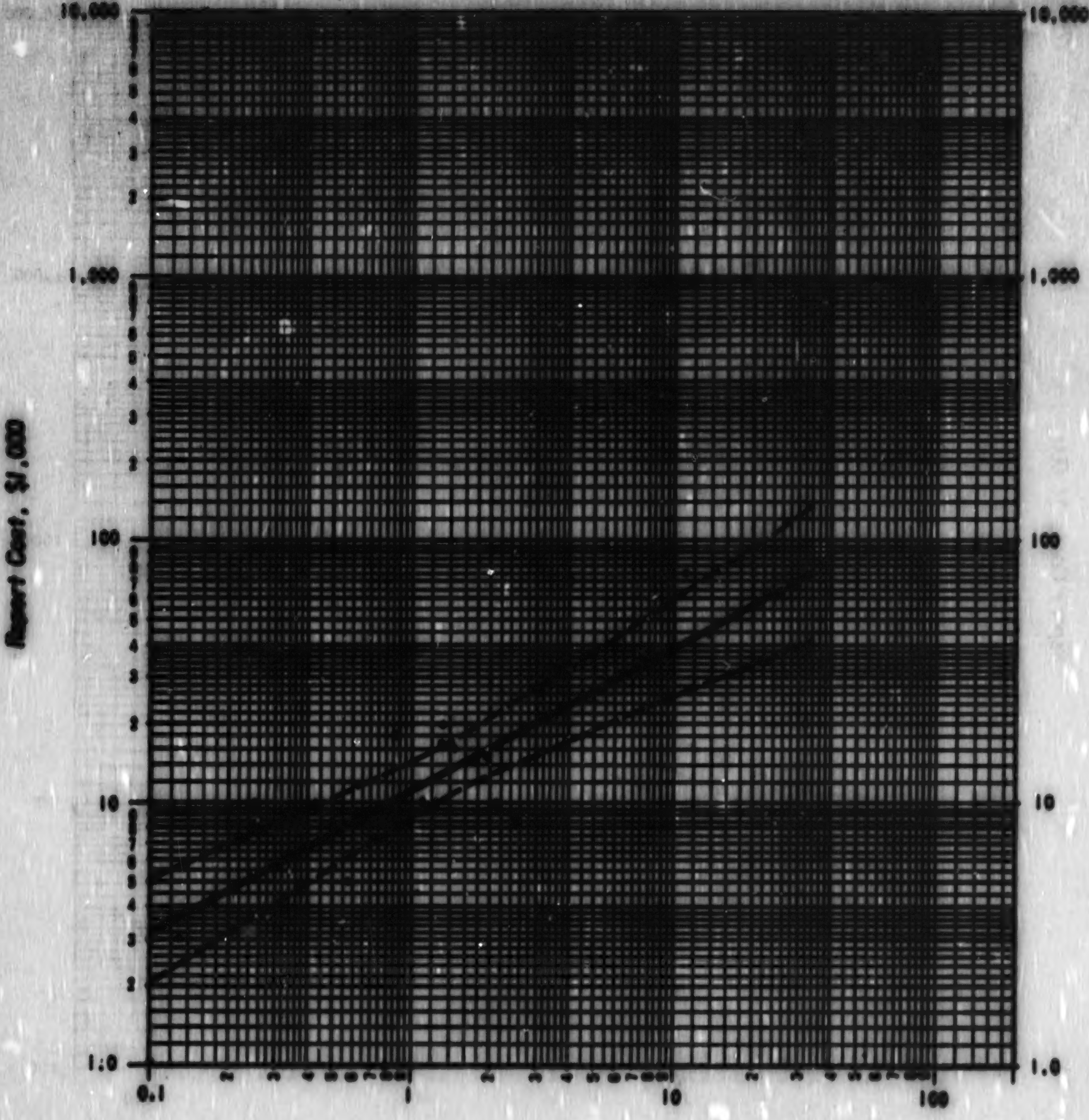


Figure 6-24. Report Cost vs. Sewage Flow

- Total sewered population
- Total sewage flow

These cost curves are derived from the cost estimates included in approximately thirty Infiltration/Inflow Analysis reports submitted to the ten EPA regional offices for review in 1974-1975 and represent the average costs one would expect in conducting the Sewer System Evaluation Survey.

However, because of the specific conditions of each sewer system, it is highly probable that the costs developed from other reliable sources for a particular sewer system are completely off the aforementioned cost curves. Therefore, these curves should be used only as a general guidance to determine the reasonableness of the costs generated.

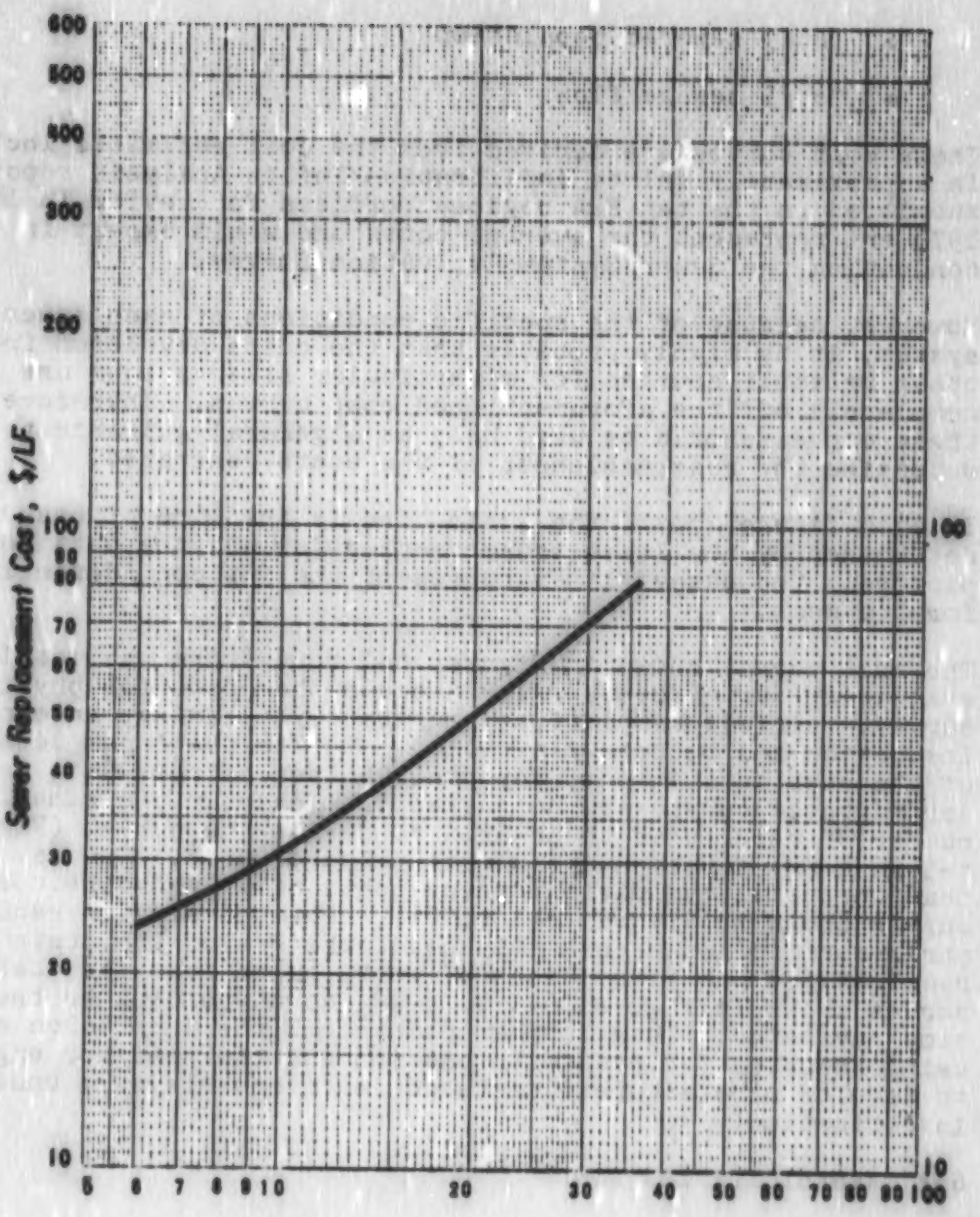
In each figure shown, the solid line is the line of best fit determined by the least square method for all the data points plotted. The dashed lines represent the 95% confidence limits for the mean.

The cost curves shown in Figures 6-1 to 6-4 are the total evaluation survey costs which include the costs for physical survey, rainfall simulation, preparatory cleaning, internal inspection and report preparation. Due to the incompleteness of the cost data in some reports, the set of cost data used to derive these curves are not taken from exactly the same number of reports as those used to derive the curves (Figures 6-5 to 6-24) for each individual phase of work. One may find that the total evaluation survey costs taken from the cost curves shown in Figures 6-1 to 6-4, corresponding to each parameter, do not necessarily equal the sum of the costs required for the five phases of work, taken from the cost curves shown in Figures 6-5 to 6-24, corresponding to the same parameter. This further points out the importance of using these cost curves with caution and the need for engineers to develop more accurate costs for each sewer system under investigation.

6.3 REHABILITATION COSTS

6.3.1 Sewer Replacement Costs

The cost curve for replacing the existing gravity sewer with a new pipe of the same size is shown in Figure 6-25. Included in the costs are the costs for site preparation, excavation, backfill, pavement, pipe materials, removal of existing pipe, pipe installation, reconnection of one house service connection for every 20 feet of pipe and field inspection. In



Pipe Size, Inches

Figure 6-25. Sewer Replacement Cost vs. Pipe Size

deriving the cost curve, it was assumed that the depth of cover over the crown of the pipe is 9 feet, the pipe is laid in moderately wet soil conditions, the excavations are limited to earth excavations and the cost required to remove the existing pipe is 50% of that required to install the new pipe. The cost required for sewage bypassing during construction is not included.

For preliminary estimations, this curve should be sufficient in most applications. For more detailed cost estimations, which may be required in the Sewer System Evaluation Survey, individual costs should be developed based on the actual field conditions. Factors which may affect the cost for sewer replacement are shown in Table 6-6.

6.3.2 Pipe Lining (Polyethylene) Costs

The cost curve for pipe lining with polyethylene pipe is shown in Figure 6-26. Included in the costs are the costs for site preparation, insertion pit, pipe materials, pipe welding, pipe installation, connection of one house service connection for every 20 feet of pipe, pipe sealing off in manholes and mobilization. It was assumed that the depth of cover over the crown of the sewer is 9 feet.

Factors which may affect the pipe lining cost are shown in Table 6-7. They should be considered in developing more refined cost data for the studies.

6.3.3 Grouting Costs

The costs for chemical grouting of sewer pipes are shown in Figure 6-27. The costs are developed based on the following assumptions [9]:

(a) Length of manhole section: 300 ft
(b) Type of pipe: Vitrified clay
(c) Depth of flow: Less than 20% of pipe diameter
(d) Type of joint: Factory made
(e) Joint spacing: 4 feet
(f) Access to manholes: Readily accessible
(g) Manhole opening: 21 inches
(h) Manhole diameter: 4 feet
(i) Manhole condition: Structurally sound with steps for access
(j) Manhole depths: 6-8 feet
(k) Hazardous gas: None present
(l) Random vs. successive manhole sections: All sections requiring grouting are successive
(m) Mobilization distance: Within 100 miles
(n) Weather conditions: Mild temperature and no storm
(o) Traffic control: None required
(p) Chemical grout used: Acrylamide gel or urethane foam.

TABLE 6-6

SEWER REPLACEMENT COST CRITERIA

Size of pipe

Depth of pipe

Type of service

Type of pipe

Removal of existing pipe

Number of service connections to be made

Groundwater elevation

Proximity to other utilities

Pipe transportation requirements

Infiltration allowance requirements

Access to site work

Availability of storage area for pipe materials and equipment

Availability of storage area for excavated materials

Weather conditions

Availability and cost of labor

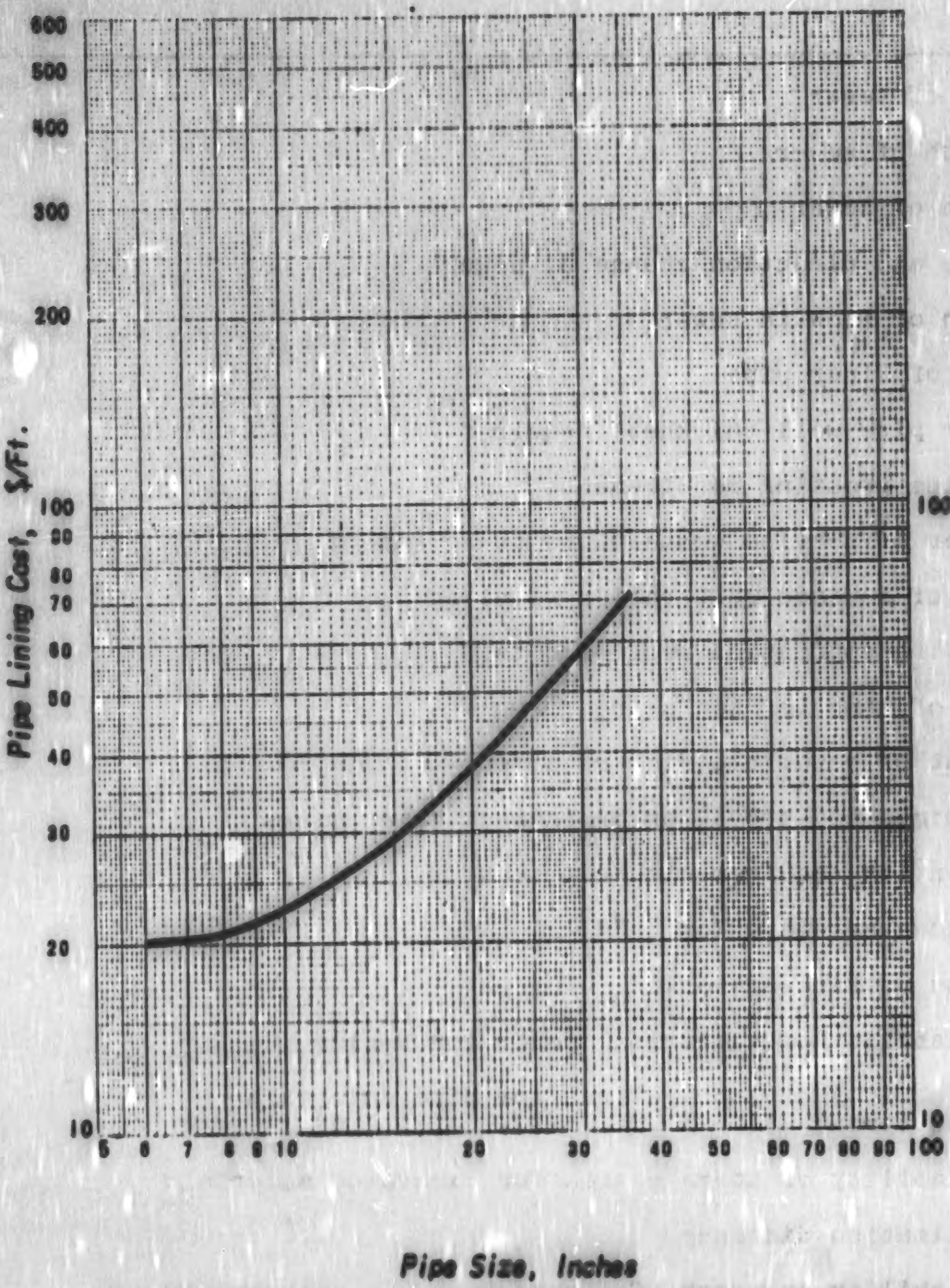


Figure 6-26. Pipe Lining (Polyethylene) Cost vs. Pipe Size

TABLE 6-7

PIPE LINING COST CRITERIA

Size of sewer

Length of sewer

Depth of sewer

Grade and direction change of sewer

Depth of flow in sewer

Size of liner pipe

Liner pipe wall thickness required

Annulus grouting requirements

Number of service connections to be made

Type of surface restoration required

Pipe transportation requirements

Type of manhole "seals" required

Extent of sewer cleaning required

Technique to "prove" or preinspect sewer lines

Excavation requirements

Groundwater elevation

Access to site of work

Availability of electrical power for fusing

Availability of storage area for pipe materials and equipment

Availability of storage area for excavated materials

Mobilization distance

Availability and cost of labor

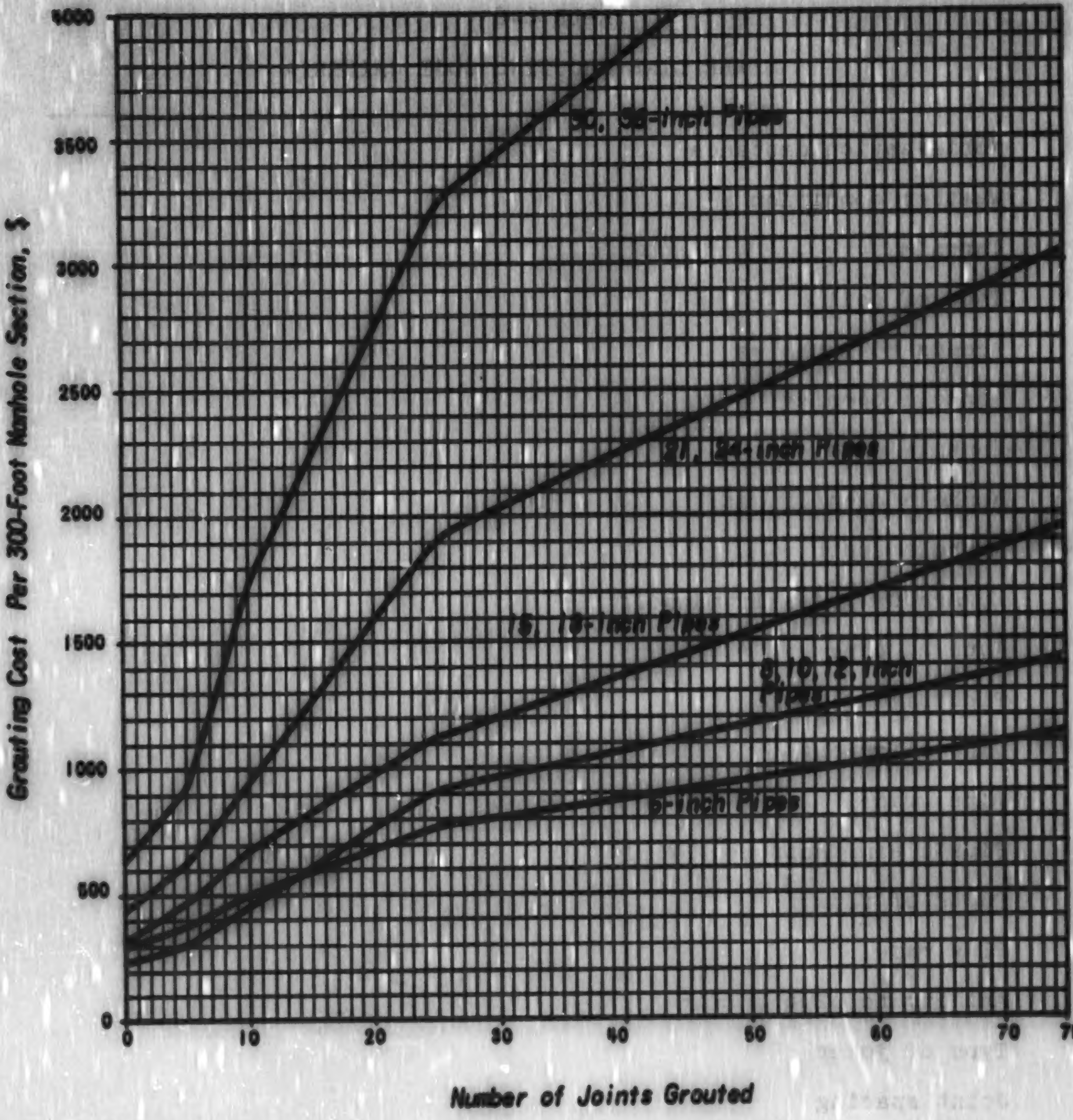


Figure 6-27. Grouting Cost vs. Number of Pipe Joints Grouted

TABLE 6-8

SEWER LINE GROUTING COST CRITERIA

Mobilization distance

Weather condition

Terrain

Type of soil

Access to manholes

Manhole opening

Manhole size

Manhole cleanliness

Manhole depth

Hazardous gases in manhole

Type of pipe

Pipe size

Pipe alignment

Pipe grade

Pipe cleanliness

Depth of flow

Flow rate

Ability to plug

Type of joint

Joint spacing

Offset joints

Intruding service connections

Structurally damaged pipe

Random vs. successive manhole sections

Availability and cost of labor

TABLE 6-9

MISCELLANEOUS REHABILITATION COSTS

Item	Unit	Cost, $/Unit
Manhole Replacement	each	500-1,000
Manhole Repair	each	50-500
Raise Manhole Frame & Cover	each	100-150
Manhole Cover Replacement	each	50-100
House Service Pipe Replacement	each	600-1,200
House Service Pipe Repair	each	200-400
Roof Leader Drain Disconnection	each	50-75
Foundation Drain Disconnection	each	300-1,200
Cellar Drain Disconnection	each	50-350
Area Drain Disconnection	each	50-350
Cross Connection Plugging	each	100-500
Drains From Springs Plugging	each	500-2,500

APPENDIX A

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17. "Costs of Wastewater Treatment by Land Application." Office of Water Program Operations, U.S. Environmental Protection Agency. Technical Bulletin, EPA-430/9-75-003 (June, 1975).

APPENDIX B

STATE CERTIFICATION

The U.S. Environmental Protection Agency has granted authorization to the States to certify if excessive infiltration/inflow does or does not exist in a sewer system tributary to a treatment works. The States have the prerogative to undertake this authorization if they desire.

The State certification information is documented in the Rules and Regulations of 40 CFR 35 Section 35-527-5. This Section states that "the Regional Administrator will determine that excessive infiltration/inflow does not exist, on the basis of State certification, if he finds that the State had adequately established the basis for its certification through submission of only the minimum information necessary to enable a judgment to be made. Such information could include a preliminary review by the applicant or State, for example of such parameters as per capita design flow, ratio of flow to design flow, flow records or flow estimates, bypasses or overflows, or summary analysis of hydrological, geographical and geological data, but this review would not usually be equivalent to a complete infiltration/inflow analysis. State certification must be on a project-by-project basis. If the Regional Administrator determines on the basis of State certification that the treatment works is or may be subject to excessive infiltration/inflow, no Step 2 or Step 3 grant assistance may be awarded except as provided in paragraph (c) of this section."

Section (c) indicates that the applicant may receive grant assistance if it is established that the treatment works will not be significantly changed by subsequent rehabilitation. The grant may be conditioned such that resulting rehabilitation be performed over some suitable implementation program.

The State certification program is intended to hasten the process of fulfilling the infiltration/inflow requirements of PL 92-500. Generally, State regulatory personnel are more familiar with the projects applying for grant assistance and thus a review of minimal data on a sewer system can provide sufficient information in which to make a judgment on excessive or nonexcessive infiltration/inflow.

State certification is not limited to applicants who provide minimal information on sewer systems but also applies to the complete structured infiltration/inflow analysis. In addition, State certification may be established on both nonexcessive and possibly excessive infiltration/inflow in sewer systems. In any event, EPA must issue the final approval of the infiltration/inflow requirements. As a result, EPA may provide a cursory or substantial review of the presented data and/or report. It is expected that in the first years of the Sewer System Evaluation Program these EPA reviews of State certified data or reports will be substantial in view of the fact that all parties involved are developing experience in this previously neglected area of planning. As time passes, it is probable that State certification of projects will receive reduced EPA review.

Currently, those States that are providing certification of infiltration/inflow data and/or reports do so by reviewing the data, working closely with those who prepared the data and then make a judgment on whether possibly excessive or nonexcessive infiltration/inflow exists. The States then submit the data and/or report to EPA with a certifying letter. The certifying letter generally contains statements which indicate the following when possibly excessive infiltration/inflow exists:

- The treatment works for which the grant application is made will not be changed by any rehabilitation program and will be a component part of any rehabilitation program.
- The grant applicant has assured that the sewer system evaluation will be completed.
- Any resulting rehabilitation program will be conducted on a schedule consistent with treatment works construction and satisfactory to the Regional Administrator.

EPA encourages the States to adopt a certification program. Cooperation among EPA, the State and the grant applicant will result in a workable program.

APPENDIX C

GLOSSARY OF TERMS

1. Combined Sewer

A sewer intended to serve as a sanitary sewer and a storm sewer, or as an industrial sewer and a storm sewer.

2. Excessive Infiltration/Inflow

The quantities of infiltration/inflow which can be economically eliminated from a sewer system by rehabilitation, as determined by cost-effectiveness analysis that compares the costs for correcting the infiltration/inflow conditions with the total costs for transportation and treatment of the infiltration/inflow.

3. Infiltration

The water entering a sewer system and service connections from the ground, through such means as, but not limited to, defective pipes, pipe joints, connections, or manhole walls. Infiltration does not include, and is distinguished from, inflow.

4. Infiltration/Inflow

The total quantity of water from both infiltration and inflow without distinguishing the source.

5. Infiltration/Inflow Analysis

An engineering and, if appropriate, an economic analysis demonstrating possibly excessive or nonexcessive infiltration/inflow.

6. Inflow

The water discharged into a sewer system, including service connections, from such sources, as but not limited to, roof leaders, cellar, yard and area drains, foundation drains, cooling water discharges, drains from springs and swampy areas, manhole covers, cross connections from storm sewers and combined sewers, catch basins, storm waters, surface run-off, street wash waters, or drainage. Inflow does not include, and is distinguished from, infiltration.

7. Internal Inspection

An activity of the Sewer System Evaluation Survey. This activity involves inspecting sewer lines that have previously been cleaned. Inspection may be accomplished by physical, photographic and/or television methods.

8. Physical Survey

An activity of the Sewer System Evaluation Survey. This activity involves determining specific flow characteristics, groundwater levels and physical condition of the sewer system that had previously been determined to contain possibly excessive infiltration/inflow.

9. Preparatory Cleaning

An activity of the Sewer System Evaluation Survey. This activity involves adequate cleaning of sewer lines prior to inspection. These sewers were previously identified as potential sections of excessive infiltration/inflow.

10. Rainfall Simulation

An activity of the Sewer System Evaluation Survey. This activity involves determining the impact of rainfall and/or runoff on the sewer system. Rainfall Simulation may include dyed water or water flooding of storm sewer sections, ponding areas, stream sections and ditches. In addition, other techniques such as smoke testing and water sprinkling may be utilized.

11. Rehabilitation

Repair work on sewer lines, manholes and other sewer system appurtenances that have been determined to contain excessive infiltration/inflow. The repair work may involve grouting of sewer pipe joints or defects, sewer pipe relining, sewer pipe replacement and various repairs or replacement of other sewer system appurtenances.

12. Sanitary Sewer

A sewer intended to carry only sanitary and industrial wastewaters from residences, commercial buildings, industrial plants and institutions.

13. **Sewer System Evaluation Survey**

A systematic examination of the tributary sewer systems or subsections of the tributary sewer systems that have demonstrated possibly excessive infiltration/inflow. The examination will determine the location, flow rate and cost of correction for each definable element of the total infiltration/inflow problem.

14. **Storm Sewer**

A sewer intended to carry only storm waters, surface run-off, street wash waters, and drainage.

APPENDIX D

METRIC CONVERSION TABLE

English Unit	Abbreviation	Multiplier	Abbreviation	Metric Unit
Cubic feet per minute	cu ft/min	0.0283	cu m/min	Cubic meters per minute
Degree fahrenheit	°F	0.555 (°F-32)	°C	Degree celsius
Feet	ft	0.305	m	Meters
Gallons	gal	0.0038	cu m	Cubic meter
Gallons per capita per day	gpcd	0.0038	cu m/capita/day	Cubic meters per capita per day
Gallons per day	gpd	0.0038	cu m/day	Cubic meters per day
Gallons per day per inch-mile	gpd/in-mile	0.0009	cu m/day/cm km	Cubic meters per day per centimeter-kilometer
Gallons per minute	gpm	0.0038	cu m/min	Cubic meters per minute
Inches	in.	2.54	cm	Centimeters
Miles	mi	1.61	km	Kilometers
Million gallons per day	mgd	0.0038	million cu m/day	Million cubic meters per day
Pounds	lbs	0.454	kg	Kilograms
Pounds per cubic foot	lbs/cu ft	16.02	kg/cu m	Kilograms per cubic meter
Pounds per gallon	lbs/gal	0.12	gm/cc	Grams per cubic centimeter
Pounds per square inch	psi	70.31	gm/sq cm	Grams per square centimeter

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